Restoration measures for coastal habitats in the Baltic Sea: cost-efficiency and areas of highest significance and need

Co-funded by the European Union

Species and biotopes

2021

HELCOM

ACTION

Co-funded by the European Union

This publication has been produced as part of the project "Actions to evaluate and identify effective measures to reach GES in the Baltic Sea marine region (HELCOM ACTION)". Running from January 2019 to December 2020, HELCOM ACTION is a Helsinki Commission (HELCOM) coordinated project that is co-funded by the European Union. The project is designed to contribute to the update of the HELCOM Baltic Sea Action Plan by 2021 and can also be used by HELCOM Contracting Parties that are also EU Member States in updating and implementing their MSFD Programme of Measures. Information and views expressed in this publication are the authors' own and might vary from those of the Helsinki Commission or its members.

helcom.fi/helcom-at-work/projects/action/

This publication is a deliverable of the HELCOM ACTION project's work package WP2 - Impacts on the seabed: evaluating restoration measures in coastal areas and impacts of spatial regulation of offshore fisheries, including effects on benthic communities and costs of measures

For bibliographic purposes this document should be cited as:
Restoration measures for coastal habitats in the Baltic Sea: cost-efficiency and areas of highest significance and need. HELCOM ACTION (2021)

Contibutor(s): Patrik Kraufvelin, Jens Olsson, Ulf Bergström, Andreas Bryhn and Lena Bergström (SLU)

Special thanks: State and Conservation, PRESSURE, EN BENTHIC

General information about the HELCOM ACTION project

EU programme concerned
Marine Strategy Framework Directive - Second Cycle: Implementation of the New GES Decision and Programmes of Measures

Reference number of the call for proposals
DG ENV/MSFD 2018 call

Title of the project
Actions to evaluate and identify effective measures to reach GES in the Baltic Sea marine region (HELCOM ACTION)

Grant agreement number
110661/2018/794637/SUB/ENV.C2

Name of beneficiary of grant agreement
Baltic Marine Environment Commission – Helsinki Commission (HELCOM)

Official legal form
Intergovernmental Organisation

Official registration number
Not applicable

Official address
Katajanokanlaituri 6B, 00160 Helsinki, Finland

Name and title of the Project Coordinator
Owen Rowe, Project Manager

Name of partners in the project and abbreviations used
Finnish Environment Institute (SYKE)
Technical University of Denmark (DTU)
Aarhus University (AU)
Tallinn University of Technology (TTU)
Swedish Agency for Marine and Water Management (SwAM)
Swedish University of Agricultural Sciences (SLU)
University of Tartu, Estonia (UT)
Klaipėda University, Marine Research Institute (KU)

Sub-contractors
Baltic Nest Institute (BNI), Sweden
AKTiiVS, Latvia
Bionautit, Finland

Start date and end date of the reporting period
01/01/2019 – 31/12/2020

Start date and end date of the project
01/01/2019 – 31/12/2020

Restoration measures for coastal habitats in the Baltic Sea: cost-efficiency and areas of highest significance and need

Contents

1. Background and definitions

Societal and economic developments are, through human activities, causing many pressures on natural coastal ecosystems that lead to changes in state (Borja & Dauer 2008). Thus, pressures are interfering with environmental status from the local or species scale through to biological communities (Adams 2005, Österblom et al. 2017), impacting the ability of coastal areas to maintain ecosystem functions and produce ecosystem services for human wellbeing (Beaumont et al. 2007, Micheli et al. 2013, Bryhn et al. 2020). During the past decades, many shallow coastal ecosystems have faced increased disturbance, which has led to their rapid deterioration (Crain et al. 2008, Halpern et al. 2008, Andersen et al. 2015, HELCOM 2018). In temperate areas, such as in the Baltic Sea, recruitment areas for fish, biogenic reefs and vegetated bottoms are especially threatened by many human activities (Kraufvelin et al. 2018, 2020c). Negative changes in the coastal zone are often caused by several activities and stress factors that are acting simultaneously, for instance different kinds of coastal construction and recreation, increased input of nutrients and other pollutants, selective harvesting of species, introduction of non-indigenous species, and climate change (Elliott 2004, Korpinen et al. 2012, Andersen et al. 2015, Worm 2016). Typical effects, seen globally, are that biological communities are becoming more and more similar (homogenisation), important top predators are decreasing in abundance and size, habitat-forming species are decreasing and the structural diversity, connectivity and process dynamics within biological communities is being disturbed (Geist & Hawkins 2016).

Normally, natural ecosystems can recover from low or moderate levels of human activities/pressures. Depending on the temporal and spatial scales, as well as the frequencies and intensities of the pressures, ecosystems may be returned to pre-stress conditions in a number of ways (Connell & Slatyer 1977). The prerequisites for this are, however, that the pressures can be reduced to tolerable levels and that the physical, chemical and biological changes that have taken place are reversible. A return to pre-stress conditions can passively take the trajectory of natural recovery or it can be reached through active restoration measures undertaken by humans (Simenstad et al. 2006, Elliott et al. 2007, 2016).

Primary goals of restoration are often to re-establish ecological functions and ecosystem services that are important for humans and to reinstall the system to a previous historical condition that is self-sustaining and resistant towards disturbance. One example of restoration is when historically destroyed wetlands are returned into sustainable ecosystems by the use of active measures, so that they again can deliver functioning ecosystem services (Borja et al. 2010, Elliott et al. 2016). After a longer period of damage, however, a return to natural conditions can be inaccessible with respect to both hydromorphology and biological processes (Hilderbrand et al. 2005, Duarte et al. 2009). Wrongly applied, some measures undertaken can also by themselves impose pressures on the environment, rather than contribute to an improvement (Kraufvelin et al. 2020bc). This may suggest that it, in many cases, may be wiser to aim at a rehabilitation that strives to improve the damaged ecosystem into a more functional condition, rather than a full restoration that aims at an original historical condition, which may not be achievable. However, the finally preferred solution in a given location is often context-specific.

Recently, the possibilities of, and potential for marine restoration have received a broadened interest within both the scientific and marine management sectors (Borja 2014, Bas et al. 2016, France 2016, Niner et al. 2017, Duarte et al. 2020). According to Borja (2014), one of the great challenges within marine ecosystem ecology is to learn how to recreate the structure and function of damaged marine ecosystems through active restoration. Another challenge listed by Borja (2014) is to understand the relationship between human pressures and their effects on ecosystems. The latter theme is central in the HELCOM ACTION report of WP 2.1 and also in a Swedish national report by Kraufvelin et al. (2020c) focusing on physical pressures and biological effects. With regard to marine restoration, there is a great need for a toolbox for active measures that can be applied broadly in various marine and brackish water areas. This is partly due to the current poor state of the marine environment in many coastal areas. It is also due to the fact that natural processes of recovery (passive restoration) and targeted measures within management, such as formal protection (see Knowlton et al. 2012, De'ath et al. 2012, Abelson et al. 2016), are often insufficient to return ecosystems to pre-disturbed conditions.

Restoration basically means to use physical (sometimes chemical) or biological measures to recreate natural physical and biological processes in an ecosystem that has been damaged or degraded due to disturbance or loss. Sometimes the term restoration can also be used when ecosystem recovery is initiated or facilitated. The disturbances can be due to human activities such as the direct effects of discharges of pollutants or nutrients or they can be due to exploitation (e.g. extraction or construction), but they can also be due to indirect interaction effects through climate change or the release of non-indigenous species. Principally, a restoration can be of two major types. Either a historical ecosystem is targeted or a new ecosystem is constructed where it has not occurred before. The former case is represented by ecological restoration, while the latter case is better known as some kind of environmental compensation (Moksnes et al. 2016a).

Even though there is a growing body of knowledge of marine restoration activities, especially in coastal ecosystems, marine restoration as a scientific or management area is still premature. Our knowledge is especially scarce when it comes to restoration of open marine systems (Elliott et al. 2007, 2016). The main reasons behind this lack of knowledge are that many natural physical processes in the sea that are still quite poorly understood. Furthermore, our knowledge about how human activities are affecting these processes, as well as how resistant and resilient marine ecosystems are, is also a clear gap (Carter 1989, Elliott et al. 2016, Ounanian et al. 2018). Similarly, we lack a lot of knowledge about the connectivity and openness of different marine ecosystems, i.e. fundamental information to achieve marine green infrastructures. According to Geist & Hawkins (2016) and Jones et al. (2018), it is much easier to carry out restoration measures in freshwater ecosystems, while in marine ecosystems, one may have to focus more on using processes of natural recovery. The challenges within marine restoration are further complicated by different sources of uncertainty such as incomplete knowledge, unpredictability and ambiguity, all of which are factors that must be dealt with by the practical restorers (Ounanian et al. 2018).

In this report, the term restoration is used broadly to describe a multitude of measures carried out to improve conditions in marine ecosystems and aiming at redirecting the systems towards conditions that prevailed before the damage. Thus, our interpretation of the restoration term also covers rehabilitating measures. One reason for using this interpretation is that this is also how the term is perceived by many laymen, professional practitioners, managers and researchers alike. The aims with restoration can then also be said to be closer to the ones defined by Clewell et al. (2000), who defined the purpose of restoration as to recreate functioning ecosystems with sufficiently high biodiversity for natural recovery over longer time perspectives rather than to recreate a natural unaffected (pristine) historical condition. In practice, this is also mostly the best that one can achieve within a restoration project, especially when longer term and larger scale damages are dealt with. This is partly due to shifting baselines (Hilderbrand et al. 2005, Duarte et al. 2009, 2015) which can make it impossible to reach historical conditions. It may also be due to regime shifts (Scheffer et al. 2001) locking ecosystems into new configurations that can be hard or even impossible to unlock with usual restoration measures, especially as restoration measures may often be on relatively more local scales.

Ecological restoration is itself the handicraft to carry out practical implementation of actions needed to recreate specific habitats or even an ecosystem. Both from a scientific and a legal perspective, however, it is important to define what the purposes are of the different types of applied restoration measures and to clearly establish the goals (Moksnes et al. 2016a). Many restoration attempts are carried out without clearly established goals, with the possible exception of a few individual target species for which the post-restoration conditions may have been defined beforehand.

In order to make the restoration efforts effective and successful, it is necessary to involve people with ecological competence and a broad understanding about how different habitats or ecosystems function. Additionally, it is also important to include people with the knowledge and background in supporting processes, all the way from the planning and funding stages to execution, monitoring and evaluation (Moksnes et al. 2016a). In order to understand how physical processes that are formative for the habitats and how they operate, it is also important to involve oceanographers and people with broad hydromorphological competence (Kraufvelin et al. 2020b). According to Jackson et al. (1995) and Aronson (2010), five main disciplines must be considered when a restoration project is carried out:

- **ecology –** information/knowledge about structure (patterns) and function (processes) in nature that is collected through historical, analytical and experimental studies,
- **formal and informal norms of the society –** information about political goals and demands as well as different groups' acceptance of these norms,
- **culture –** such as traditional use of an area or a resource,
- **economy –** what kind of geographical areas or habitats are considered worthy of restoration,
- **politics –** are there goals, values and demands driven or counteracted by political wills.

There are also a number of case specific and practical questions that need to be answered in connection with any restoration project, such as:

- Which activities and pressures have caused the change/damage/loss?
- Is it possible to restore the species, habitat, foodweb and/or function?
- How efficient are different measures?
- Towards what environmental state are the measures aiming?
- What are the costs of the measures?
- What ecosystem services, human values and societal benefits are provided by a successful restoration?
- Will positive restoration effects be persistent over time?
- What scale of restoration is planned and what is the expected scale of effect from the restoration?

In this report, we aim to provide answers to at least some of these questions. Regarding the question about what has caused the damage or the decrease in status, then physical and mechanical pressures are often relatively easy to identify, as long as there are no apparent signs of multiple and additive pressures. For single species, it may then be especially important to find ”bottlenecks” that have a big influence on population sizes through effects on mortality or reproduction. For fish stocks, for example, it can be important to look at habitat availability as a restricting factor. This is because early life stages are often sensitive to environmental changes and the availability of good spawning and nursery areas can influence the stock size (Sundblad et al. 2014).

Different alternatives for restoration can be visualised in a highly simplified manner with ecosystem structure on the x-axis and ecosystem processes on the y-axis (Figure 1, after Bradshaw 1996). Full restoration of a damaged ecosystem would ideally take us from the open circle in the lower left to the filled circle at the upper right. A rehabilitation may not take us all the way to the undisturbed/pristine state, but can still represent a clear improvement in ecosystem status. It should be noted that an improvement may also lead away from the path heading towards the original ecosystem and present a much steeper trajectory, i.e. the measure becomes more of the type ”replacement”.

The aquatic physicochemical conditions, the hydromorphological traits and the species themselves present in a habitat represent the major components of a restoration project. Even though natural recovery processes should always be used, if possible (Bradshaw 1996), all of these three components demand specific attention during the process. Sometimes it can *de facto* be enough to rely on natural processes for ”restoration” as soon as the damaging pressure has decreased to appropriate levels or has been removed, provided the environmental background conditions are favourable. For example in deeper marine areas such as the sea floor disturbed by bottom trawling (Jones et al. 2018), or more generally in open systems (Geist & Hawkins 2016), natural recovery can in itself represent one of the most important ”restoration measures”. In many cases, passive and natural recovery could possibly be a first choice to regain important ecosystem functions and ecosystem services and then active restoration measures could be undertaken, if the recovery from damage is characterized as too slow (Jones et al. 2018). The cheapest and simplest ”measure” is still to use all possible ways to avoid and minimise damage as long as this is possible. Thus, a mitigation hierarchy needs to be applied and followed in the management of activities that may impose pressure on the environment. This means to first avoid damage, then to minimise damage and finally, as a last alternative, to restore/compensate for damage (Naturvårdsverket 2016, Jacob et al. 2018). In most cases, it becomes much cheaper to avoid and minimise damage when the activities are going on than to afterwards try to restore what has been lost or degraded (Naturvårdsverket 2016).

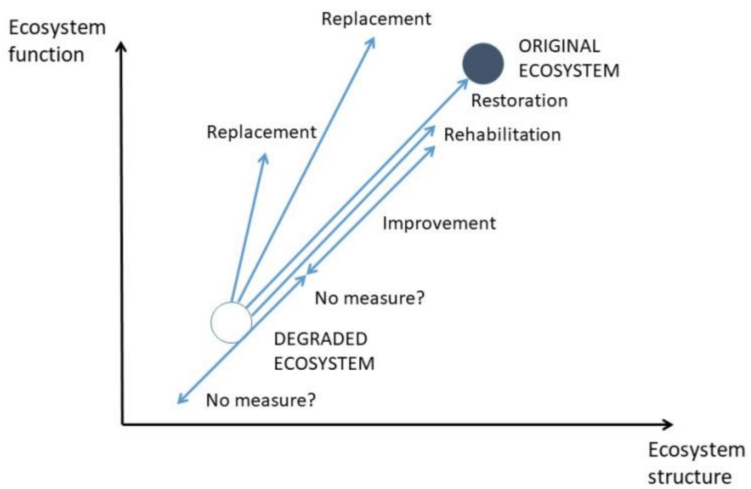

Figure 1. Different alternatives for restoration where the targeted ecosystem structure (on the x-axis) is put in relation to the ecosystem processes (on the y-axis) that also are involved (after Bradshaw 1996). With ‘Original ecosystem’ a pristine or undisturbed ecosystem is understood.

Since a restoration process is ongoing/continuous, while ecological responses to different restoration measures at the same time are seldom linear, it is often difficult to judge if a measure is successful or not. A central goal for a restoration measure thus needs to be that the ecosystem can develop in an unrestricted positive direction after the measure has been taken (Bradshaw 1996). The restoration process should lead to measurable progress in ecosystem condition where both abiotic and biotic thresholds may need to be surpassed (see figure 3a in Hobbs & Harris 2001). Usually, hydromorphological and chemical improvements are targeted first followed by biological improvements. When the desired condition has been achieved, it may then be enough to focus management actions on maintaining the condition.

However, there is still a risk that examples of successful restorations may falsely lead to a belief that it is always possible to recreate what has been damaged or lost. It is therefore important to acknowledge that, within marine restoration, there is no *silver bullet* that we can always rely on as a universal solution. A fundamental prerequisite for a successful restoration is that the factors initially causing the damage on the habitat or ecosystem have disappeared or can be kept at a minimum that is known not to cause a detrimental impact. Some habitat forming species such as mussels and seaweeds require hard substrates for their establishment and such a substrate might not be available any longer in the disturbed area. Due to this, some sort of structuring restoration measures that return hard surfaces to the area may be required. This could be done by creating suitable benthic structures, for example, artificial reefs (Seaman 2007), artificial substrates (George et al. 2015), stony reefs (Støttrup et al. 2014) or mussel shell banks (Dolmer et al. 2009, Morris et al. 2019), in order to physically restore the environment.

The choice of area may also be a crucial factor within the restoration process. If a habitat has never been naturally present in an area, the abiotic or biotic prerequisites for the habitat are probably lacking, and thereby successful restoration is conceivably low. Similarly, it can be difficult to restore a habitat in an area where the environmental background conditions have changed radically. Examples of this can be areas where eelgrass meadows or perennial macroalgal belts have been damaged due to the construction of marinas causing shadowing and altered light conditions or where changed light and bottom conditions due to eutrophication make large areas unsuitable for recolonization.

To be able to assess the success of restoration efforts, it is important to establish reference conditions, to specify and clarify the goals of the restoration activities, and agree upon what level of restored condition is the aim, neither should an evaluation of the chances for long-term success be forgotten. These aspects are very important but are often overlooked. The reference conditions should describe both habitat structures and functions, but also the biological, chemical and physical processes that are creating and maintaining the structures and systems (Kraufvelin et al. 2020b). Restoration for improving connectivity between areas also has to be a priory in the perspective of green infrastructure. This may for example concern the inclusion of protected areas, restored areas, migration barriers, rivers, fladas, wetlands and water ways (Berkström et al. 2019). Measures should also be undertaken with evident perspectives on global climate change in such a way that it is evaluated if the restored systems are resilient enough to changing conditions, as well as if the restored systems even can be adapted to assist with the mitigation and dampening of the negative effects of climate change.

It is also equally important to evaluate the restoration measures and their success through quantitative follow-up studies. This can be done by following the development of the target features in a restored area over time. These kinds of monitoring investigations can be done through a BA-design, which means that there are data available both before and after the restoration measures (BA before–after). The end result can also be compared with the conditions in unrestored reference systems using a CI-design, which means that there are data from the restored area as well as from an unrestored reference area (CI control–impact). More comprehensive follow-up programs, where the aim is to establish cause-effect relationship and allow for scientific analyses, need to apply a BACI-design (before-after-control-impact; see Stewart-Oaten et al. 1986, Underwood 1994, Schmitt & Osenberg 1996) in order to cover all relevant dimensions. These BACI-investigations include multiple measurements before and after the restoration measures, both in the target water area as well as in similar reference areas (preferably there are more than one reference area) where the restoration measures have not been carried out.

An important reason for the lack of monitoring after restoration measures have been carried out is the lack of long-term funding (Harper & Quigley 2005). Proper evaluation is of central importance to clarify what has worked well and what has not worked out as planned and how future measures should be developed and executed more (cost) effectively. In addition, information collected through well designed monitoring studies can also often be used scientifically to document different ecological processes involved in possible success stories, but also in revealing reasons for possible failures (see also Moksnes et al. 2016a). To develop the knowledge base and cost-efficiency of restoration efforts, it is therefore essential that funding is allocated for thorough evaluation of different measures.

Restoration is an iterative process, which needs to follow these important steps in order to achieve maximum success:

1. Investigate previous historical and current reference conditions with regard to water chemistry, hydromorphology and biology.
2. Choose a suitable area.
3. Draw up a well-anchored restoration target or several step-wise targets.
4. Develop a restoration plan.
5. Apply for and get permissions, whenever required, and carry out the practical work.
6. Choose suitable indicators for monitoring.
7. Evaluate the undertaken measures (for example when it comes to hydromorphogy or responses in plant and animal communities) as well as the monitoring works afterwards.

In the Baltic Sea area, experiences of marine restoration measures are still very restricted (Naturvårdsverket 2016, Kraufvelin et al. 2020b). Globally, however, a great deal has been invested in marine restoration in many, often more densely populated and economically significant, areas (Bayraktarov et al. 2016). Typical target habitats for restoration are seagrass beds (Fonseca 2011, Orth et al. 2011), oyster reefs (Brumbaugh et al. 2000, Coen et al. 2007), mangrove forests (Ellison 2000, Lewis 2005) and coral reefs (Epstein et al. 2001, Meesters et al. 2015) with a general focus on biogenic habitat-forming structures/features. While these habtat types may not all be present in the Baltic Sea region important lessons can be learned and t he need for, and the interest in, marine restoration in the Baltic Sea area will certainly increase. This because many areas have been damaged by construction works, by pollution and excessive nutrient loads or by excessive harvesting of marine resources. This is also due to increased global environmental threats such as climate change. Demands for restoration activities are included within European environmental directives and of central interest for actions to recover environmental status in the Baltic Sea. In order to be able to apply the most relevant and cost efficient measures possible, functioning methods of restoration need to be developed, described, tested in practice, and thoroughly evaluated.

As part of the HELCOM ACTION project (Actions to evaluate and identify effective measures to reach good environmental status in the Baltic Sea marine region), this current report gives a overview of knowledge withinin the field of marine restoration ecology and evaluates a number of restoration measures for coastal habitats in the Baltic Sea with specific emphasis on their feasibility and cost effectiveness. At the same time, coastal areas of the Baltic Sea where these restoration measures would be of highest significance/need are evaluated. The central purpose of the report is to document and present existing and relevant restoration measures and their possibilities for application in different areas of the Baltic Sea with acknowledgement of reported difficulties, weaknesses, risks and restrictions for subsequent biological recovery in both time and space.

2. Measures related to restoration of coastal habitats

Many marine coastal habitats can be suitable for some sort of restoration. Some of them have already previously been the subject of restoration measures, although with varying success. Common reasons behind failures have been that different external conditions, for example the water quality, have not improved at the same time when the restoration measures were undertaken. Due to such interlinkages, it is important to jointly look into which physical measures (targeted towards the abiotic habitat) and biological measures (targeted towards the biological habitat and the organisms), as well as possible water chemical measures, are essential for making the restoration successful. In the following sections, we review existing experiences of restoration in the Baltic Sea area habitat by habitat and measure type by measure type.

In total, this report contains information on 16 measures of potential relevance for improving coastal habitats in the Baltic Sea. The content is to be viewed as representing measures for which at least some experience is available today, and the intention of their presentation is to support their further evaluation. The measures represent three broad categories: i) measures aiming at restoring or rehabilitating[1] habitats or habitat forming species (measures 1–7 and 14 below), ii) measures aiming at reducing pressure levels (measures 9–13 below), with a focus on nutrient loading, which is a predominating pressure in many coastal habitats, and iii) measures focusing on protecting habitats or strengthening functionally important species (measures 8 and 15). In addition to the restoration measures presented in this report, other potential measures are available, such as releasing species, but as these measures have not been scientifically evaluated as thoroughly, they will not be listed here.

The measures for which information is presented in this report are:

1. Restoration of eelgrass, *Zostera marina*
2. Restoration of soft bottom macrophytes (other than eelgrass)
3. Restoration of brown macroalgae, mainly *Fucus vesiculosus*
4. Restoration of blue mussel reefs
5. Restoration of stony reefs in areas where these have previously been lost
6. Restoration of soft bottoms naturally free of vegetation
7. Restoration of coastal wetlands and fladas/lagoons
8. Strengthening piscivorous fish to rehabilitate coastal ecosystem function
9. Reducing nutrient loading by farming and harvesting blue mussels
10. Rehabilitation of hypoxic areas by oxygen pumping
11. Reducing internal phosphorus loads by metal binding
12. Investigative and trial biomanipulation by removing cyprinids and sticklebacks as a method for rehabilitating coastal ecosystems
13. Rehabilitation of anoxic, nutrient rich or polluted sediments by removal or coverage
14. Establishment of artificial reefs
15. Protection of habitats
16. Follow-up and knowledge sharing

Data for measures 1–15 are provided as thoroughly as possible under the general understanding that practical experience is still limited for most of these measures in coastal areas of the Baltic Sea. Measure 16 suggests actions to remediate this limitation in the future by enhancing follow-up and knowledge sharing. The 16 measures below synthesise work in the HELCOM ACTION project and by Kraufvelin et al. (2020b) and all the measures have also been delivered (in January 2020) as 'synopses' within the HELCOM Baltic Sea Action Plan (BSAP) Update process.

For all the measures, the following aspects are provided:

- Examples of drivers/human activities that can cause damage that needs to be restored (list taken from HELCOM template used for updating of the BSAP),
- Examples of pressures causing damage that needs to be restored (list taken from HELCOM template used for updating of the BSAP),
- State change(s) in ecosystem components calling for attention/measures,
- Practical restoration method(s),
- Geographical areas in the Baltic Sea where the restoration has been tested/attempted,
- Main expected responses/outcomes of the measure,
- Evidence of success – with reference(s),
- Examples of ecosystem services that may be influenced positively by the measure(s),
- Examples of human benefits from the measure(s),
- Target groups for the benefits in the society,
- Possible time lags before positive effects can be seen after the measures have been undertaken,
- Costs per unit "restored" structure or function, e.g. cost per area of habitat or weight (biomass unit) of compound,
- References in general.

2.1 Restoration of eelgrass, *Zostera marina*

Examples of drivers/human activities that can cause damage that needs to be restored. Restructuring of seabed morphology (dredging, beach replenishment, sea-based deposit of dredged material); Extraction of minerals (rock, metal ores, gravel, sand, shell); Fish and shellfish harvesting (bottom-touching towed gears, professional, recreational); Fish and shellfish harvesting (pelagic towed gears, stationary gears, professional, recreational); Aquaculture – marine, including infrastructure; Agriculture; Transport – shipping (incl. anchoring, mooring); Transport – shipping infrastructure (harbours, ports, ship-building); Tourism and leisure infrastructure (piers, marinas); Tourism and leisure activities (boating, beach use, water sports, etc.).

Examples of pressures causing damage that needs to be restored. Disturbance of species: Visual, presence, boating, recreational activities, above-water noise; Extraction of target fish and shellfish species and incidental fish catches; Physical disturbance to seabed (temporary or reversible and recovers within 12 y); Physical loss (due to permanent change of seabed substrate or morphology and to extraction of seabed substrate); Changes to hydrological conditions; Input of nitrogen; Input of phosphorus; Input of organic matter — diffuse sources and point sources.

State change(s) in ecosystem components calling for attention/measures. Decreased distribution of eelgrass on soft and sandy bottoms in many regions of the Baltic Sea, for instance in western and southern Sweden and in Denmark, but also in the Northern Baltic Proper. Often, the extent of the decrease is unknown as there is a lack of "historical" information on distributions. To some extent, old aerial photographs may help in this mapping.

Practical restoration method(s). Transplantation of vegetative eelgrass shoots.

Geographical areas in the Baltic Sea where the restoration has been tested/attempted. Skagerrak (County of Bohuslän) on the Swedish west coast; Kattegat (Gothenburg harbour); Kalmar Sound in Southeastern Sweden; Skåne (southern Sweden); Southern Denmark; Estonia; Åland Sea. Research project at Tvärminne in Gulf of Finland is studying recovery in mixed macrophyte communities with eelgrass *Zostera marina* and angiosperms (Gustafsson, Kauppi & Salo unpubl.).

Main expected responses/outcomes of the measure. The measure is primarily relevant in areas where eelgrass occurs and/or has occurred naturally, i.e. in areas with suitable salinity and substrate type. In large parts of the Baltic Sea, however, eelgrass has a lower natural occurrence compared to other macrophytes.

Successful restoration of eelgrass could improve ecosystem structure and several ecosystem functions (habitat-forming, supporting biodiversity, fish nursery areas, CO_2 sinks, coastal protection through wave-dampening and sediment stabilisation, sequestration of nutrients and organic matter, etc.).

Evidence of success - with reference(s).

From western Sweden (Skagerrak/Kattegat), there are examples of successful results from restoration of eelgrass at the experimental scale. Transplantation of vegetative shoots has proven to be the only feasible method, while for example seeding does not work. The method is still both expensive and time consuming (Cole & Moksnes 2016, Eriander et al. 2016, Infantes et al. 2016, Moksnes et al. 2016a, b). The measure is only effective provided that the pressures originally causing the eelgrass loss also are removed, for example pressures related to water quality. Recently, the role of local physical regime shifts such as changes in light and physical sediment conditions and how and why these events prevent eelgrass recovery have been investigated (Moksnes et al. 2018).

For some other areas where eelgrass is present (such as southern Sweden, Denmark and the northern Baltic Proper), relatively little information is currently available on the validity of the measure. For the northern Baltic Proper (Estonia, Åland Sea), some success with the transplantation of eelgrass has been reported after the first growing season using a rope substrate method (Gagnon et al. 2019, Pajusalu et al. 2019). However, the transplanted eelgrass did not survive the winter. In another attempt to transplant eelgrass in the northern Baltic Proper, the overall shoot density decreased, but on some ropes, the number of shoots increased significantly (Pajusalu et al. 2019). At Tvärminne in the Gulf of Finland, recovery has recently been studied in mixed macrophyte communities with eelgrass and angiosperms (Gustafsson, Kauppi & Salo unpubl.).

Examples of ecosystem services that may be influenced positively by the measure(s). Primary production, Food web dynamics, Habitat, Biodiversity, Resilience, Climate and atmospheric regulation, Biological regulation, Regulation of eutrophication, Sediment retention, Food, Raw material, Recreation, Aesthetic values, Science and education, etc.

Examples of human benefits from the measure(s). Less impact from eutrophication on: society (e.g. blooms), on commercial and recreational fisheries, as well as on recreational activities. Less physical damage to shores, properties and infrastructure. Mitigation of climate change impacts. Access to eelgrass as raw material for building (roofs, isolation) and fertilization. Access to fish as food through commercial and recreational fisheries. Access to wrasses for salmon delousing in fish farms. Direct, intellectual, aesthetical and non-user values for recreation, research, education and well-being.

Target groups for the benefits in the society. Local inhabitants by the coast, professional fishermen, recreational fishermen, fish farmers, businessmen within tourism, tourists.

Possible time lags before positive effects can be seen after the measures have been undertaken. Estimated time lags are at ca 1–2 years (Moksnes et al. 2016a, b).

Costs per unit "restored" structure or function, e.g. cost per area of habitat or weight (biomass unit) of compound. Costs are estimated to 120 000 – 250 000 euro per hectare eelgrass meadow for the approach used in western Sweden (Moksnes et al. 2016ab). However, Bayraktarov et al. (2016) give a median price for the western world of 392 988 euro per hectare restored seagrass and de Groot et al. (2013) present a range of 250 000 – 600 000 euro per hectare for coastal systems including seagrasses.

References in general. Davis & Short 1997, van Katwijk et al. 1998, 2009, 2016, Orth et al. 1999, 2011, de Jonge 2000, Worm & Reusch 2000, Calumpong & Fonseca 2001, Short et al. 2002, Seddon 2004, Park & Lee 2007, Marion & Orth 2010, Fonseca 2011, de Groot et al. 2013, Zhou et al. 2014, Zhang et al. 2015, Cole & Moksnes 2016, Eriander et al. 2016, Infantes et al. 2016, Moksnes et al. 2016a, b, 2018, Yang et al. 2016, Zhao et al. 2016, Gagnon et al. 2019, Pajusalu et al. 2019, https://www.lansstyrelsen.se/kalmar/stat-och-kommun/miljo/vatten/restaurering-av-marina-miljoer.html#0, https://www.novagrass.dk/en/home/.

2.2 Restoration of soft bottom macrophytes (other than eelgrass)

Examples of drivers/human activities that can cause damage that needs to be restored. Canalisation and other watercourse modifications (coastal dams, culverting, trenching, weirs, large-scale water deviation); Restructuring of seabed morphology (dredging, beach replenishment, sea-based deposit of dredged material); Fish and shellfish harvesting (bottom-touching towed gears, professional, recreational); Fish and shellfish harvesting (pelagic towed gears, stationary gears, professional, recreational); Aquaculture – marine, including infrastructure; Agriculture; Forestry; Transport – shipping (incl. anchoring, mooring); Transport – shipping infrastructure (harbours, ports, ship-building); Waste waters (urban, industrial, and industrial animal farms); Tourism and leisure infrastructure (piers, marinas); Tourism and leisure activities (boating, beach use, water sports, etc.).

Examples of pressures causing damage that needs to be restored. Disturbance of species: Visual, presence, boating, recreational activities, above-water noise; Extraction of target fish and shellfish species and incidental fish catches; Physical disturbance to seabed (temporary or reversible and recovers within 12 y); Physical loss (due to permanent change of seabed substrate or morphology and to extraction of seabed substrate); Changes to hydrological conditions; Input of nitrogen; Input of phosphorus; Input of organic matter — diffuse sources and point sources.

State change(s) in ecosystem components calling for attention/measures. Decreased distribution of macrophytes and charophytes on soft bottoms.

Practical restoration method(s). Harvesting undesired competing vegetation, transplantation and seeding of macrophytes, transplantation of overwintering propagules.

Geographical areas in the Baltic Sea where the restoration has been tested/attempted. Many examples from lakes on the European continent and from e.g. Sweden, few experiences from the Baltic Sea; project in Björnöfjärden, Stockholm archipelago, eastern Sweden (http://balticsea2020.org/alla-projekt/overgodning/15-oevergoedning-avslutade-projekt/402-restaurering-av-vegetationsklaedda-bottnar); A research project at Tvärminne in the Gulf of Finland is studying recovery in mixed macrophyte communities with eelgrass *Zostera marina* and angiosperms (Gustafsson, Kauppi & Salo unpubl.).

Main expected responses/outcomes of the measure. Successful restoration of soft bottom macrophytes could improve ecosystem structure and several ecosystem functions, such as habitat-forming, supporting biodiversity, fish nursery areas, CO_2 sinks, coastal protection through wave-dampening and sediment stabilisation, sequestration of nutrients and organic matter, etc. Negative responses: possible conflicts with small boat traffic, swimming and other recreational use. Success may demand simultaneous improvements in the environment through: phosphorus inactivation by aluminium addition, biomanipulation, removal of nutrient rich sediment, sediment covering, etc. Sometimes it may also be necessary to manipulate the amount of grazing animals.

Evidence of success – with reference(s). Some success has been achieved for restoration of macrophytes within lake restoration on the European continent, with technical guidance available e.g. in Hilt et al. (2006) and Bakker et al. (2013). Swedish information from lakes and rivers is given in the report by Degerman et al. (2017), while Torn et al. (2010) give some information about brackish-water charophytes in Estonia. The methods from freshwater systems can potentially be used also in brackish water areas (Shafer & Bergstrom 2010), although they are largely untested outside the freshwater realm (Kraufvelin et al. 2020b). Some methods used within eelgrass restoration may also work for other soft bottom macrophytes/angiosperms. A research project at Tvärminne, Gulf of Finland, has recently studied recovery in mixed macrophyte communities with both eelgrass and angiosperms (Gustafsson, Kauppi & Salo unpubl.). The success of restoration of macrophytes on soft bottoms may demand simultaneous improvements in the environment through: phosphorus inactivation by aluminium addition, biomanipulation, removal of nutrient rich sediment, sediment covering, etc. Sometimes it may also be necessary to manipulate the amount of grazing animals (Kraufvelin et al. 2020a). More research, testing and documentation are needed to see if active restoration measures used in these communities increase the rate of recovery or how well the communities recover, compared to just removing the pressures and allow for natural recovery (passive restoration).

Examples of ecosystem services that may be influenced positively by the measure(s). Primary production, Food web dynamics, Habitat, Biodiversity, Resilience, Climate and atmospheric regulation, Biological regulation, Regulation of eutrophication, Sediment retention, Food, Raw material, Recreation, Aesthetic values, Science and education, etc.

Examples of human benefits from the measure(s). Less damage from eutrophication in the society, on commercial and recreational fisheries as well as on recreation. Less damage from climate change. Access to macrophytes as raw material for building (roofs, isolation) and fertilization. Access to fish as food through commercial and recreational fisheries. Direct, intellectual, aesthetical and non-user values for recreation, research, education and well-being.

Target groups for the benefits in the society. Local inhabitants by the coast, professional fishermen, recreational fishermen, businessmen within tourism, tourists.

Possible time lags before positive effects can be seen after the measures have been undertaken. Estimated time lags may be ca 1–2 years (estimate from Moksnes et al. 2016ab). However according to Hilt et al. (2006) and Bakker et al. (2013), re-establishment of plant communities is a very slow process which often comprises 20–40 years.

Costs per unit "restored" structure or function, e.g. cost per area of habitat or weight (biomass unit) of compound. Costs per restored hectare are possibly comparable with those for seagrass or ca 120 000 – 600 000 euro per hectare (de Groot et al. 2013, Bayraktarov et al. 2016, Moksnes et al. 2016ab).

References in general. Bachmann et al. 1999, Smart & Dick 1999, van Nes et al. 2002, Hilt et al. 2006, Gulati et al. 2008, Ailstock et al. 2010a, b, Shafer & Bergstrom 2010, Torn et al. 2010, Reuterskӧld 2012, Bakker et al. 2013, de Groot et al. 2013, Rodrigo et al. 2013, 2015, Ogdahl & Steiman 2015, Cooke et al. 2016, Cronk & Fennessy 2016, Degerman et al. 2017, Zinko 2017, https://www.lansstyrelsen.se/kalmar/stat-och-kommun/miljo/vatten/restaurering-av-marina-miljoer.html#0 and the project

Levande kust (www.balticsea2020.org/alla-projekt/overgodning/14-oevergoedning-pagaende-projekt/54-levande-kustzon).

2.3 Restoration of brown macroalgae, mainly *Fucus vesiculosus*

Examples of drivers/human activities that can cause damage that needs to be restored. Land claim; Coastal defence and flood protection (seawalls, flood protection); Restructuring of seabed morphology (dredging, beach replenishment, sea-based deposit of dredged material); Extraction of minerals (rock, metal ores, gravel, sand, shell); Fish and shellfish harvesting (bottom-touching towed gears, professional, recreational); Fish and shellfish harvesting (pelagic towed gears, stationary gears, professional, recreational); Aquaculture – marine, including infrastructure; Agriculture; Forestry; Transport – shipping (incl. anchoring, mooring); Transport – shipping infrastructure (harbours, ports, ship-building); Waste waters (urban, industrial, and industrial animal farms); Tourism and leisure infrastructure (piers, marinas); Tourism and leisure activities (boating, beach use, water sports, etc.).

Examples of pressures causing damage that needs to be restored. Disturbance of species: Visual, presence, boating, recreational activities, above-water noise; Extraction of target fish and shellfish species and incidental fish catches; Physical disturbance to seabed (temporary or reversible and recovers within 12 y); Physical loss (due to permanent change of seabed substrate or morphology and to extraction of seabed substrate); Changes to hydrological conditions; Input of nitrogen; Input of phosphorus; Input of organic matter — diffuse sources and point sources.

State change(s) in ecosystem components calling for attention/measures. Decreased distribution of perennial brown macroalgae on hard bottoms.

Practical restoration method(s). Transplantation of seaweed attached to stones/boulders in areas where brown macroalgae have been lost or their distribution has decreased significantly (Kautsky et al. 2019, 2020). Seeding of kelp on "green gravel" (Fredriksen et al. 2020), enhancement of *ex situ* recruitment (Verdura et al. 2018), direct seeding (Verdura et al. 2018), transplantation of adult individuals (Carney et al. 2005), removal of local herbivores (Tracey et al. 2014), use of artificial reefs (Carney et al. 2005).

Geographical areas in the Baltic Sea where the restoration has been tested/attempted. Björnöfjärden, Stockholm archipelago, eastern Sweden; Himmerfjärden, Trosa archipelago, eastern Sweden; Kalmar Sound, southeastern Sweden; Bay of Gdansk, Poland; Kiel bight, Germany.

Main expected responses/outcomes of the measure. Successful restoration of brown macroalgae could improve ecosystem structure and support several functions, such as habitat-formation, biodiversity, fish nursery areas, CO_2 sinks, coastal protection through wave-dampening, sequestration of nutrients and organic matter, etc.

The measure is relevant in areas where bladder-wrack occurs or has occurred naturally, i.e. in areas with suitable salinity and substrate type. In large parts of the Baltic Sea, i.e. the inner and outer parts, bladder-wrack is less important compared to other macrophytes. For Denmark and western Sweden, restoration of seaweed also seems less relevant, unless it is linked to reef restoration, as settlement of macroalgae typically occurs rapidly, at least during spring/summer (Kraufvelin et al. 2010, 2020a). Most hard substrates on reefs/stone areas in the photic zone of the western Baltic Sea have macroalgal growth. For the more saline areas of the western Baltic Sea, however, restoration of various kelp species may be more relevant, for example sugar kelp in combination with nutrient decrease (Moy et al. 2008, Bekkby & Moy 2011, Moy & Christie 2012, Fredriksen et al. 2020).

Evidence of success – with reference(s). Restoration through transplantation of bladder-wrack is very difficult and still no real success stories exist from the Baltic Sea (see Kautsky et al. 2019, 2020 for details), with some possible exceptions (see Krost et al. 2018). The methods have been used without long-term success, e.g. for bladderwrack in the Baltic Sea (Engkvist et al. 2000, Berger et al. 2001, Kautsky et al. 2019, 2020) or with limited success in shallow water for some species of brown algae in the Oslofjord in Norway (Christie & Fredriksen 2011), but see Krost et al. (2018) from the Kiel bight in Germany. Before attempting bladder-wrack restoration, it has to be clarified that the external growth conditions for the species are suitable. In areas where bladder-wrack has completely disappeared, restoration has proven difficult due to grazers rapidly consuming transplanted bladder-wrack specimens (e.g. Engkvist et al. 2000, Berger et al. 2001, Kautsky et al. 2019, 2020). Kautsky et al. (2019, 2020) have prepared a thorough guideline for bladder-wrack restoration on the Swedish east coast (northern Baltic Proper) and they list epiphytic load, light conditions, grazing and type of substratum as factors that need to be taken into consideration in order to achieve successful restoration of bladder-wrack. They also provide in depth information about how to practically accomplish bladder-wrack restoration (Kautsky et al. 2019, 2020).

There are also methods available for restoring sugar kelp along the Skagerrak-coast of Norway in combination with nutrient decrease (Moy et al. 2008, Moy & Christie 2012). In these cases, suitable areas for restoration should be mapped beforehand (Bekkby & Moy 2011). Recently, there are some promising results for the restoration of sugar kelp in the Norwegian part of Skagerrak using a technique referred to as seeded “green gravel” (Fredriksen et al. 2020). Gravel were seeded with kelp and reared in the laboratory until the algae reached 2–3 cm when the gravel was transferred to the field. The planted kelp showed high survival and growth over nine months, even when dropped from the surface. The applied technique is cheap, simple, does not require scuba diving or highly trained field workers and it can be up-scaled to treat large areas and even to introduce genes from more resilient kelp populations onto vulnerable kelp forests (Fredriksen et al. 2020). This method can also overcome propagule limitation and lack of hard substrate (Gorgula & Connell 2004, Burek et al. 2018) and there is no destructive harvest and transplantation of donor macroalgal individuals (Fredriksen et al. 2020). A number of different methods have also been used for restoration of kelp in Chile (Westermeier et al. 2014) and in Canada (Heath & Chambers 2014).

Examples of ecosystem services that may be influenced positively by the measure(s). Primary production, Food web dynamics, Habitat, Biodiversity, Resilience, Climate and atmospheric regulation, Biological regulation, Regulation of eutrophication, Sediment retention, Food, Raw material, Recreation, Aesthetic values, Science and education, etc.

Examples of human benefits from the measure(s). Less damage from eutrophication in the society, on commercial and recreational fisheries as well as on recreation. Less physical damage on shores, properties and infrastructure. Less damage from climate change. Access to kelp as raw material for fish feed, etc. Access to fish as food through commercial and recreational fisheries. Access to wrasses for salmon delousing in fish farms. Direct, intellectual, aesthetical and non-user values for recreation, research, education and well-being.

Target groups for the benefits in the society. Local inhabitants by the coast, professional fishermen, recreational fishermen, fish farmers, businessmen within tourism, tourists.

Possible time lags before positive effects can be seen after the measures have been undertaken. At least 4–5 years for bladder-wrack, *Fucus vesiculosus*, in the Baltic Sea, since this is the time needed for the macroalgal individuals to reach reproductive age (Kautsky et al. 2019, 2020). For restoration of kelp by using the “green gravel” technique, the time lags still remain to be tested, but there are indications that they may be considerably shorter (Fredriksen et al. 2020).

Costs per unit "restored" structure or function, e.g. cost per area of habitat or weight (biomass unit) of compound. Costs for restoration of *Fucus vesiculosus* in the Baltic Sea have been estimated by Kautsky et al. (2020) and they present the time required for various stages connected with transplanting a certain number of bladder-wrack individuals, including a follow-up program. In total 464 hours are estimated to be needed for planning, actual transplantation and following up of the transplantation success for 350 bladder-wrack individuals. For restoring 1 m^2 of kelp forest through different measures the following costs have been reported: seeding on “green gravel” 6.23 euro (Fredriksen et al. 2020), enhancement of *ex situ* recruitment 105 euro (Verdura et al. 2018), direct seeding 43 euro (Verdura et al. 2018), transplantation 5–142 euro (Carney et al. 2005), removal of local herbivores 2 euro (Tracey et al. 2014), artificial reefs 7 euro (Carney et al. 2005). Globally, de Groot et al. (2013) present a range of 250 000–600 000 euro per hectare for coastal systems including perennial macroalgae on rocky shores. The presented costs for macroalgal restoration, depending on species, geographical region and method, vary internationally with several orders of magnitudes; from 20 000–26 000 euros (Tracey et al. 2014, Campbell et al. 2014) to 2 300 000 euro per hectare (Carney et al. 2005). Globally, de Groot et al. (2013) present a range of 250 000 – 600 000 euro per hectare for coastal systems including perennial macroalgae on rocky shores. The presented costs for macroalgal restoration, depending on species and geographical region, vary internationally with several orders of magnitudes; from 26 012 euro (Campbell et al. 2014) to 2 285 880 euro per hectare (Carney et al. 2005).

References in general. Engkvist et al. 2000, Berger et al. 2001, Gorgula & Connell 2004, Carney et al. 2005, Moy et al. 2008, Zweifel 2008, Pålsson 2009, Salonsaari 2009, Bekkby & Moy 2011, Moy & Christie 2012, de Groot et al. 2013, Campbell et al. 2014, Heath & Chambers 2014, Tracey et al. 2014, Westermeier et al. 2014, Yoon et al. 2014, Burek et al. 2018, Krost et al. 2018, Verdura et al. 2018, Kautsky et al. 2019, 2020, Fredriksen et al. 2020, www.marbipp.tmbl.gu.se/, www.balticsea2020.org/alla-projekt/overgodning/14-oevergoedning-pagaende-projekt/54-levande-kustzon, http://balticsea2020.org/alla-projekt/overgodning/14-oevergoedning-pagaende-projekt/566-restaurering-av-blastangssamhaellen-en-manual-foer-tillvaegagangssaett, https://www.lansstyrelsen.se/kalmar/stat-och-kommun/miljo/vatten/restaurering-av-marina-miljoer.html#0).

2.4 Restoration of blue mussel reefs

Examples of drivers/human activities that can cause damage that needs to be restored. Land claim; Coastal defence and flood protection (seawalls, flood protection); Restructuring of seabed morphology (dredging, beach replenishment, sea-based deposit of dredged material); Extraction of minerals (rock, metal ores, gravel, sand, shell); Renewable energy generation (wind, wave and tidal power), including infrastructure; Fish and shellfish harvesting (bottom-touching towed gears, professional, recreational); Fish and shellfish harvesting (pelagic towed gears, stationary gears, professional, recreational); Aquaculture – marine, including infrastructure; Transport – shipping (incl. anchoring, mooring); Transport – shipping infrastructure (harbours, ports, ship-building); Waste waters (urban, industrial, and industrial animal farms); Tourism and leisure infrastructure (piers, marinas); Tourism and leisure activities (boating, beach use, water sports, etc.).

Examples of pressures causing damage that needs to be restored. Input or spread of non-indigenous species; Disturbance of species: Visual, presence, boating, recreational activities, above-water noise; Extraction of target fish and shellfish species and incidental fish catches; Physical disturbance to seabed (temporary or reversible and recovers within 12 y); Physical loss (due to permanent change of seabed substrate or morphology and to extraction of seabed substrate); Changes to hydrological conditions; Input of nitrogen; Input of phosphorus; Input of organic matter — diffuse sources and point sources; Input of other substances (e.g. synthetic substances, non-synthetic substances, radionuclides) — diffuse sources, point sources, atmospheric deposition, acute events.

State change(s) in ecosystem components calling for attention/measures. Decreased distribution of biogenic blue mussel reefs on hard bottoms. This far, mainly local decrease in mussel abundance has been reported, but in western Sweden (Kattegat and Skagerrak), a larger-scale decrease and disappearance of blue mussels seem to be taking place as reported by both scientists and people collecting mussels for recreational purposes (Andersen et al. 2016, Frigstad et al. 2018, Havsoch vattenmyndigheten 2020, Christie et al. 2020). Especially blue mussel reefs on soft bottoms seem to be declining or have even disappeared (Svedberg 2019).

Practical restoration method(s). The measure aims to support and strengthen natural populations of blue mussel (*Mytilus edulis/trossulus*) in areas where mussel abundances are decreasing due to human activities, unbeneficial environmental factors or increased predation by birds and mesopredatory fish and crabs. This can be achieved by deploying mussel shells (for example from mussel farms) as recruitment substrates or other natural or artificial substrates onto bottoms in areas with natural availability for mussel recruits. Alternatively, mussels can be naturally recruited onto (jute or coconut fibre fabric) substrates in the water mass and later transplanted to the bottom together with the substrate. Direct transplantation of adult mussels is another option and may be especially relevant in areas with a high predation pressure on juvenile blue mussels by eider ducks, mesopredatory fish (e.g. wrasses) or shore crabs (Christie et al. 2020) that are consuming juvenile mussels and impacting the recruitment to the adult population. The use of mussels from mussel farms may be a way to get around the predation on juvenile mussels, but transplantation methods need to make sure to have the right genetical base for the restored area and to take caution not to spread diseases or parasites. The recruitment to some coastal areas may in itself also be restricted and strengthening recruitment substrates may work if the substrate is the restricting factor for the recruitment. In some areas, however, minimizing pressures on blue mussel reefs might be more efficient than undertaking active restoration measures.

Choosing the most suitable site(s) for restoration could also be examined more closely. Normally, restoration is attempted on “historical” sites and this does not always need to be the best alternative, although the recreation of previous occurrences should be targeted. Alternatively, the conditions around existing mussel reefs could be studied and quantified and these could be compared with localities where the reefs have been lost to see if the conditions have changed and use the information to maybe find more suitable locations. The use of artificial surfaces deployed in the sea which could be tailor-made to favour mussels could also be examined more closely. This applies to docks, piers, harbours, windfarm and bridge fundaments that all have the potential to serve as good mussel environments (Lindegarth et al. 2019).

Geographical areas in the Baltic Sea where the restoration has been tested/attempted. Halsefjord and Stigfjorden, western Sweden (in Skagerrak); Limfjorden, northern Denmark; Nørrefjord, southern Denmark.

Main expected responses/outcomes of the measure. Successful restoration of blue mussel reefs could improve ecosystem structure and several functions, such as habitat-forming, supporting biodiversity, supporting food web productivity, reducing turbidity, coastal protection through wave-dampening, sequestration of nutrients and organic matter, etc. Some negative responses may be present such as possible conflicts with boat navigation and that the new habitat may demand space from other marine habitats.

Evidence of success – with reference(s). The measure is relevant in areas where blue mussels occurs and/or have occurred naturally, i.e. in areas with suitable salinity and substrate type. The listed methods for restoration can in Denmark lead to fast re-establishment, within 1–2 years, of functional/harvestable mussel stands (Dolmer et al. 2009). Successful restoration of biogenic reefs of mussels have been observed to increase the structural complexity and biodiversity of the habitat and associated fauna, which may support an increased fish growth and diversity over time (Kristensen et al. 2015). The restoration may also include many positive side effects, such as mussels serving as habitats for associated organisms and fish, clearer waters and increased coastal protection (Kraufvelin et al. 2020b). As restoration projects focusing on mussel reefs still are rare, there is not much information available on follow ups, maybe with the exception of Dolmer et al. (2009) and Kristensen et al. (2015).

Examples of ecosystem services that may be influenced positively by the measure(s). Primary production, Food web dynamics, Habitat, Biodiversity, Resilience, Climate and atmospheric regulation, Biological regulation, Regulation of eutrophication, Sediment retention, Food, Raw material, Recreation, Aesthetic values, Science and education, etc.

Examples of human benefits from the measure(s). Less damage from eutrophication in the society, on commercial and recreational fisheries as well as on recreation. Less physical damage on shores, properties and infrastructure. Less damage from climate change. Access to mussels as food, feed and raw material. Access to fish as food through commercial and recreational fisheries. Access to wrasses for salmon delousing in fish farms. Direct, intellectual, aesthetical and non-user values for recreation, research, education and well-being.

Target groups for the benefits in the society. Local inhabitants by the coast, professional fishermen, recreational fishermen, fish farmers, mussel farmers, businessmen within tourism, tourists.

Possible time lags before positive effects can be seen after the measures have been undertaken. The time lags for positive effects to be seen are probably roughly comparable to the values encountered when establishing mussel farming, but with a certain delay due to slower mussel growth on the bottom compared to what is the case for mussel growth in the water mass. The time is also dependent on geographical location (i.e. salinity, amount of food for the mussels); thus 1–3 years could be a realistic number.

Costs per unit "restored" structure or function, e.g. cost per area of habitat or weight (biomass unit) of compound. Blue mussel restoration is probably one of the least costly marine restoration methods, provided that the measures are successful. Still, no cost estimates seem to exist for restoration of blue mussel reefs in the Baltic Sea. For indicative global comparison, a median cost of 194 270 euro per hectare restored oyster reef is given by Bayraktarov et al. (2016), while de Groot et al. (2013) present a range of 250 000 – 600 000 euro per hectare for coastal systems including rocky shores. Grabowski et al. (2012) give an achieved economical value for oyster reef ecosystem services around 5 000 – 90 000 euro per hectare and year (without oyster harvest) and estimate the reefs to return their restoration costs in 2 – 14 years. If the reefs are subjected to destructive oyster harvest, however, they will not return the restoration costs (Grabowski et al. 2012).

References in general. Crisp 1967, Holt et al. 1998, Brumbaugh et al. 2000, Mann & Powell 2007, Dolmer et al. 2009, Beck et al. 2011, Elsäßer et al.. 2013, de Groot et al. 2013, Baggett et al. 2015, George et al. 2015, Kristensen et al. 2015, Sharma et al. 2016, Kraufvelin et al. 2020b, Christie et al. 2020).

2.5 Restoration of stony reefs in areas where these have previously been lost

Examples of drivers/human activities that can cause damage that needs to be restored. This refers to past activities. Restructuring of seabed morphology (dredging, beach replenishment, sea-based deposit of dredged material); Extraction of minerals (rock, metal ores, gravel, sand, shell); Transport – shipping infrastructure (harbours, ports, ship-building).

Examples of pressures causing damage that needs to be restored. Physical disturbance to seabed (temporary or reversible and recovers within 12 y); Physical loss (due to permanent change of seabed substrate or morphology and to extraction of seabed substrate); Changes to hydrological conditions.

State change(s) in ecosystem components calling for attention/measures. Loss of hard surfaces through exploitation, stone fishing, marine extraction.

Practical restoration method(s). Restoration and revitalization of stony/boulder habitats is a priority in areas where these habitats have previously been destroyed or lost due to human activities. These measures are undertaken in order to bring back the degraded habitat to a state where it can support biodiversity and also possibly the productivity of fish populations. The measures aim to re-establish natural physical hard structures, and are mainly applicable for the southern and south-western Baltic Sea. In practice, the restoration measure comprises reintroduction of natural or blasted rocks that can serve as underwater stony/boulder reefs to allow for the colonisation of hard bottom macroalgal and macrofaunal assemblages, including crustaceans, mussels and fish. The main difference from deploying artificial reefs is that restoration of stone reefs is done to counteract historical losses using natural substrates/materials, while the artificial reefs are rather deployed for modifying the natural underwater seascape using artificial substrates/materials.

Geographical areas in the Baltic Sea where the restoration has been tested/attempted. Læsø Trindel, Kattegat, Denmark; Vinga stony reefs outside Gothenburg, Sweden. Mainly in Denmark and to a lesser extent in Sweden.

Main expected responses/outcomes of the measure. The measure is relevant for coastal areas where stony reefs have previously been present, but where they are now depleted, such as in the southern and south-western Baltic Sea. There are mostly local positive effects of the measures, but with a combination of the establishment of marine protected areas, some wider scale positive impact may be achieved. Positive responses: more habitat for marine organisms, increased biodiversity, preserved ecosystem services, improved coastal protection against erosion, sequestration of organic material and nutrients, etc. Negative responses: altered bottom structure, impact on water circulation, effects on soft bottom organisms, the new habitat may demand space from other marine habitats, introduced hard substrates in areas of predominating soft bottoms can serve as stepping stones for non-indigenous invasive species competing with native species, promoting "attraction by individuals" ahead of "production" can lead to overharvesting of certain species. Whether the observed increases are pure attraction effects of the fish or if they also reflect effects at the population abundance level, is not established due to a lack of long-term follow-up studies. However, combining the measure with protection from fishing is important to facilitate rapid re-establishment and to avoid over-fishing. It may also be relevant to observe if natural predators such as seals and cormorants are gathered around the reefs as fish are expected to become easier to catch in areas where they aggregate, such as around restored stone reefs.

Evidence of success – with reference(s). In the Baltic Sea region, a restoration was applied in Denmark to areas where the original hard substrate historically has been removed by stone fishing, leaving a soft, predominantly sandy substrate that could not support the natural biological community including fish. When stone reefs were re-introduced, it was observed that the biotic community changed as the new structures attracted species with a preference for rocky habitats. Monitoring in such areas have shown increased biodiversity, increased abundances of fish, including increased abundance of larger specimens of certain species of fish (Støttrup et al. 2014, 2017) and even harbour porpoise (Mikkelsen et al. 2013). Several other projects are also going on in Denmark to restore stone reefs to increase bottom area and reach GES. In Sweden, measures such as the restoration of lost stone reefs, alongside the use of artificial reefs, are under consideration for instance by the Swedish Marine and Water Management Agency (SwAM), although currently the measure is not regarded as being of a very high priority, but merely to have a low national potential.

Similar effectiveness of the measure can be deduced from monitoring fish close to offshore wind farms in the Sound area, where boulders are deployed as scour protection around the turbine foundations (Bergström et al. 2013, Stenberg et al. 2015). Comparable examples can also be found from areas outside of the Baltic Sea (HELCOM 2018). At Vinga in Sweden, there has also been an Increase in commercially important fish species such as cod and saithe (Egriell et al. 2007, Wikström et al. 2016) and increase in shellfish and other benthic life forms (Salonsaari 2009, Pålsson 2009).

Examples of ecosystem services that may be influenced positively by the measure(s). Primary production, Food web dynamics, Habitat, Biodiversity, Resilience, Climate and atmospheric regulation, Sediment retention, Food, Recreation, Aesthetic values, Science and education, etc.

Examples of human benefits from the measure(s). Less physical damage on shores, properties and infrastructure. Access to macroalgae, mussels and oysters as raw material, food and feed. Access to fish as food through commercial and recreational fisheries. Access to wrasses for salmon delousing in fish farms. Direct, intellectual, aesthetical and non-user values for recreation, research, education and well-being.

Target groups for the benefits in the society. Local inhabitants by the coast, professional fishermen, recreational fishermen, fish farmers, mussel farmers, businessmen within tourism, tourists

Possible time lags before positive effects can be seen after the measures have been undertaken. Positive effects on macroalgae and small macroinvertebrates probably occur rapidly, within weeks and months (Egriell et al. 2007). However, ca 2–3 years are needed for significant positive effects on lobster and fish to occur from constructed stony reefs combined with establishment of marine protected areas (Wikström et al. 2016).

Costs per unit "restored" structure or function, e.g. cost per area of habitat or weight (biomass unit) of compound. The local positive effects of restoring stony reefs are high, but since this kind of restoration is very expensive, the restored areas are very small. Restoration of 7 hectares and stabilisation of 6 hectares of stony reefs at Læsø Trindel in Denmark costed 4 800 000 euro (Støttrup et al. 2014, 2017). The construction and monitoring of seven stony reefs (more of the artificial reef type, see point 14 below) at Vinga outside Gothenburg in Sweden costed about 1 200 000 euro (Salonsaari 2009, Wikström et al. 2016).

References in general. Egriell et al. 2007, Salonsaari 2009, Pålsson 2009, Bulleri & Chapman 2010, Malm & Engkvist 2011, Degraer et al. 2011, Chapman 2012, Mikkelsen et al. 2013, Støttrup et al. 2014, 2017, Bergström et al. 2015, Stenberg et al. 2015, Dafforn et al. 2015, Wikström et al. 2016, www.naturstyrelsen.dk/naturbeskyttelse/naturprojekter/blue-reef/.

2.6 Restoration of soft bottoms naturally free of vegetation

Examples of drivers/human activities that can cause damage that needs to be restored. Canalisation and other watercourse modifications (coastal dams, culverting, trenching, weirs, large-scale water deviation); Restructuring of seabed morphology (dredging, beach replenishment, sea-based deposit of dredged material); Extraction of minerals (rock, metal ores, gravel, sand, shell); Transmission of electricity and communications (cables); Fish and shellfish harvesting (bottom-touching towed gears, professional, recreational); Transport – shipping (incl. anchoring, mooring); Tourism and leisure activities (boating, beach use, water sports, etc.).

Examples of pressures causing damage that needs to be restored. Disturbance of species: Visual, presence, boating, recreational activities, above-water noise; Disturbance of species: Other (e.g. barriers, collision); Extraction of target fish and shellfish species and incidental fish catches; Physical disturbance to seabed (temporary or reversible and recovers within 12 y); Physical loss (due to permanent change of seabed substrate or morphology and to extraction of seabed substrate);

Changes to hydrological conditions; Input of organic matter — diffuse sources and point sources.

State change(s) in ecosystem components calling for attention/measures. Disturbed/damaged bottoms after e.g. construction and cable work or due to eutrophication (e.g. accumulation of drifting algae).

Practical restoration method(s). Damaged unvegetated soft bottoms can be restored through covering the seafloor with new bottom material e.g. after coastal construction works or by collection and removal of e.g. drifting macroalgae to re-establish bottoms naturally free from vegetation. Possible measures may also include natural (passive) resedimentation of previously dredged waterways when these are no longer in use.

Geographical areas in the Baltic Sea where the restoration has been tested/attempted. Åland islands; western Sweden, etc.

Main expected responses/outcomes of the measure.

Examples of positive responses of these measures are: re-establishment of previous habitats and bottom substrates for bottom fauna as well as reproductive areas for fish. Among negative responses there are: risks for changed or unnatural sediment composition (as it is very difficult to reconstruct the right proportions of sand, mud and gravel making up the seafloor), risks of removing important species while removing macroalgae.

The recovery process depends on which species are present in the area and their respective life cycles, mobility and capability of dispersal (Lewis et al. 2002). Recolonization of plants (in the photic zone) and animals (in the photic and aphotic zone) are typical positive responses. If the surface sediment is removed or altered, however, a biogeochemically active layer with associated functions disappear with potential consequences for the recovery (Hulth & Sundbäck 2009). Experiments have shown that lower levels of bottom living microalgae restrict the recolonization of macrofauna (Stocks & Grassle 2001). Full recovery after measures such as dredging is probably restricted both by a slow or seasonal recruitment and by the availability of food (see Norkko et al. 2006 for references). The spatial scale of the disturbance seems to be the most crucial factor for the speed, succession and completeness of the recolonising macrofauna community (Lewis et al. 2002, Bolam et al. 2006, Norkko et al. 2006). The recovery of flora and fauna can possibly be boosted by leaving undisturbed refugia in the treated area that can serve as local banks for a recolonization (Hulth & Sundbäck 2009).

Evidence of success – with reference(s). Active restoration may often be quite complicated to achieve and passive resedimentation may in many cases be preferable. The measure is sometimes mandatory in connection with seabed installations, such as cable works.

Examples of ecosystem services that may be influenced positively by the measure(s). Food web dynamics, Habitat, Biodiversity, Resilience, Sediment retention, Food, etc.

Examples of human benefits from the measure(s). Less damage from eutrophication in the society, on commercial and recreational fisheries as well as on recreation. Access to fish as food through commercial and recreational fisheries. Direct, intellectual, aesthetical and non-user values for recreation, research, education and well-being.

Target groups for the benefits in the society. Local inhabitants by the coast, professional fishermen, recreational fishermen, businessmen within tourism, tourists.

Possible time lags before positive effects can be seen after the measures have been undertaken. Positive responses for the macrofauna occur pretty fast during spring and summer seasons, i.e. within weeks and months (Lewis et al. 2002). For the fish, it depends of the time of the year which means from immediate positive responses to within 1 year.

Costs per unit "restored" structure or function, e.g. cost per area of habitat or weight (biomass unit) of compound. Cooper et al. (2013) calculated restoration costs for a dredged site of 83.9 hectare in the Thames estuary, Great Britain and reached a value of 11 252 euro per hectare. This amount included cost for restoration (dredging, capping, bed levelling), licensing, carbon footprint and survey costs (one baseline survey and two post-restoration surveys).

References in general. Pihl 2001, Lewis et al. 2002, Boyd et al. 2003, Bellew & Drabble 2004, Norkko et al. 2006, Johnson et al. 2007, Hulth & Sundbäck 2009, Cooper et al. 2013, Martinsson 2015, Cooke et al. 2016, www.marbipp.tmbl.gu.se/

2.7 Restoration of coastal wetlands and fladas/lagoons

Examples of drivers/human activities that can cause damage that needs to be restored. This refers to past activities leading to loss of functions such as natural spawning habitats, nutrient trapping, etc. Land claim; Canalisation and other watercourse modifications (coastal dams, culverting, trenching, weirs, large-scale water deviation); Coastal defence and flood protection (seawalls, flood protection); structuring of seabed morphology (dredging, beach replenishment, sea-based deposit of dredged material); Fish and shellfish harvesting (bottom-touching towed gears, professional, recreational); Fish and shellfish harvesting (pelagic towed gears, stationary gears, professional, recreational); Aquaculture – marine, including infrastructure; Agriculture; Forestry.

Examples of pressures causing damage that needs to be restored. Loss of, or change to, natural biological communities due to cultivation of animal or plant species; Disturbance of species: Visual, presence, boating, recreational activities, above-water noise; Disturbance of species: Other (e.g. barriers, collision); Extraction of target fish and shellfish species and incidental fish catches; Physical disturbance to seabed (temporary or reversible and recovers within 12 y); Physical loss (due to permanent change of seabed substrate or morphology and to extraction of seabed substrate); Changes to hydrological conditions; Input of nitrogen; Input of phosphorus; Input of organic matter — diffuse sources and point sources

State change(s) in ecosystem components calling for attention/measures. Disturbance to and loss of shallow bay habitats, fladas/lagoons, coastal wetlands and flooding areas. Spawning and recruitment habitats in coastal tributaries for coastal fish have undergone substantial deterioration in many regions of the Baltic Sea (Engstedt et al. 2010, Nilsson et al. 2014, Kraufvelin et al. 2018. 2020c). The measure is relevant to reduce this impact in coastal areas within the natural range of freshwater-spawning coastal fish species, where the availability of natural spawning areas is limited due to human-induced habitat loss. The positive effects are mainly local, within coastal areas, but with a potential for basin wide positive effects.

Practical restoration method(s). Recreating wetlands, through e.g. impoundments, enables periods with flooding to keep the water longer in the system. These wetlands can serve as nutrient traps, improve birdlife, improve habitats for amphibians and invertebrates, and promote the recruitment of pike and perch, but also other fish species such as cyprinids. Approximately 100 wetlands have been restored along the Swedish east coast to promote reproduction and recruitment of pike and perch. For the same purpose, fish migration obstacles have been removed in about 40 coastal streams in Sweden (Hansen et al. 2020). Similar initiatives are also ongoing in Finland and Estonia. Coastal wetlands are often popular recreational sites for nature enthusiasts. Restoration and revitalization of coastal wetlands, fladas and lagoons as spawning and recruitment habitats for fish are key priorities in areas where wetlands have previously been drained and destroyed, in order to bring back the degraded habitat to a state where it can support biodiversity and also the productivity of fish populations.

Geographical areas in the Baltic Sea where the restoration has been tested/attempted. Björnöfjärden, Stockholm archipelago, eastern Sweden; Kalmar Sound, southeastern Sweden; Gyldensteen strand, Denmark; pike factories at numerous places along the Swedish Baltic Sea coast (Swedish Anglers Association); fladas in the Quark area (in both Sweden and Finland)

Main expected responses/outcomes of the measure. Experiences of the effectiveness of restoring wetlands and tributaries to support spawning habitats of coastal fish are available from the Baltic Sea coast of Sweden. Examples of positive responses from the restoration of wetlands include maintenance of a high biological production and diversity as well as function as nutrient and sediment traps (buffering zones), promoted fish reproduction ("pike factories", perch), benefits for bird and amphibian life, recreation, etc. Increased number of predatory fish can contribute to decreased eutrophication through an increased predation on smaller fish and other prey species, both in the wetland and in the sea outside. This can in turn increase the amount of grazing zooplankton, crustaceans and gastropods controlling phytoplankton and periphyton and filamentous algae (Östman et al. 2016). The effects of restored wetlands on nutrient retention/uptake by slowing down the nutrient flux through the ecosystems and thereby combating marine eutrophication should not be forgotten either. This is an important positive side effect of many wetland restoration projects that are done explicitly to benefit fish. Negative responses include potentially disturbed terrestrial ecosystems, alteration of freshwater or marine habitats, potential harmful effects of certain bird species.

Evidence of success – with reference(s). Coastal wetlands and rivers are very important as reproductive areas for many species of coastal fish. In addition to pike, also perch and many species of cyprinids migrate to fresh water in spring for spawning (Ljunggren et al. 2011, Fredriksson et al. 2013). Presence of flooded vegetation is beneficial to the recruitment of pike (Nilsson et al. 2014). Restoration of wetlands as reproduction areas, foremost for pike, have in many cases been shown to result in a strong increase in the production of juvenile pike as a result of optimal spawning conditions, predation refuge and food production (Nilsson et al. 2014, Larsson et al. 2015, Hansen et al. 2020). Effects on adult populations are not yet well established, but some studies are ongoing (Hansen et al. 2020, see also Fredriksson et al. 2013). Ecological functions of coastal wetlands are estimated to become restored within 20 years (Borja et al. 2010). There are evident needs for improved coordination of different management measures within restoration of wetlands as well as long-term monitoring of their effects on recruitment, local fish populations and the ecosystem as a whole (Hansen et al. 2020).

Examples of ecosystem services that may be influenced positively by the measure(s). Primary production, Food web dynamics, Habitat, Biodiversity, Resilience, Climate and atmospheric regulation, Biological regulation, Regulation of eutrophication, Sediment retention, Food, Raw material, Recreation, Aesthetic values, Science and education, etc.

Examples of human benefits from the measure(s). Less damage from eutrophication in the society, on commercial and recreational fisheries as well as on recreation. Access to fish as food through commercial and recreational fisheries. Direct, intellectual, aesthetical and non-user values for recreation, research, education and well-being.

Target groups for the benefits in the society. Local inhabitants by the coast, professional fishermen, recreational fishermen, fish farmers, businessmen within tourism, tourists.

Possible time lags before positive effects can be seen after the measures have been undertaken. Generally at least one year is needed before significant increases occur in juvenile production and juvenile emigration of pike (Nilsson et al. 2014). Effects on the adult population takes considerably longer.

Costs per unit "restored" structure or function, e.g. cost per area of habitat or weight (biomass unit) of compound. For Sweden, 281 hectare wetland/coastal lakes were restored between 2010 and 2019 and 2 610 hectares were made accessible for pike by 83 measures/projects by the Swedish Anglers Association (Hansen et al. 2020). The costs for one hectare restored wetland are estimated to 10 000 – 20 000 EUR (including planning and restoration, but excluding monitoring costs afterwards). Globally, de Groot et al. (2013) present a range of 15 000 – 600 000 EUR per restored hectare for coastal wetlands.

References in general. Sandell & Karås 1995, Zedler & Callaway 1999, Warren et al. 2002, Sandström 2003, Olsson et al. 2004, Simenstad et al. 2006, Degerman 2008, Isaksson 2009, Pålsson 2009, Salonsaari 2009, Borja et al. 2010, Engstedt et al. 2010, Ljunggren et al. 2011, Staszak & Armitage 2012, Fredriksson et al. 2013, de Groot et al. 2013, Strand & Weisner 2013, Lindahl 2014, Nilsson et al. 2014, Larsson et al. 2015, Tibblin et al. 2016, Zhao et al. 2016, Östman et al. 2016, Arheimer & Pers 2017, Kraufvelin et al. 2018, Saarinen 2019, Hansen et al. 2020, www.balticsea2020.org/alla-projekt/overgodning/15-oevergoedning-avslutade-projekt/279-strandaeng-foer-gaeddyngelproduktion, https://www.lansstyrelsen.se/kalmar/stat-och-kommun/miljo/vatten/restaurering-av-marina-miljoer.html#0, https://baltcf.org/project/pike-factories-restoring-wetlands-for-natural-pike-reproduction/, http://www.avjf.dk/avjnf/naturomrader/gyldensteen-strand/ and www.gyldensteen-research.dk/.

2.8 Invigorate piscivorous fish populations to rehabilitate coastal ecosystem function

Examples of drivers/human activities that can cause damage that needs to be restored. This refers to past activities leading to loss of functions such as natural spawning habitats, etc. Land claim; Canalisation and other watercourse modifications (coastal dams, culverting, trenching, weirs, large-scale water deviation); Coastal defence and flood protection (seawalls, flood protection); structuring of seabed morphology (dredging, beach replenishment, sea-based deposit of dredged material); Fish and shellfish harvesting (bottom-touching towed gears, professional, recreational); Fish and shellfish harvesting (pelagic towed gears, stationary gears, professional, recreational); Aquaculture – marine, including infrastructure; Agriculture; Forestry.

Examples of pressures causing damage that needs to be restored. Loss of, or change to, natural biological communities due to cultivation of animal or plant species; Disturbance of species: Visual, presence, boating, recreational activities, above-water noise; Disturbance of species: Other (e.g. barriers, collision); Extraction of target fish and shellfish species and incidental fish catches; Physical disturbance to seabed (temporary or reversible and recovers within 12 y); Physical loss (due to permanent change of seabed substrate or morphology and to extraction of seabed substrate); Changes to hydrological conditions; Input of nitrogen; Input of phosphorus; Input of organic matter — diffuse sources and point sources; Input of anthropogenic sound (impulsive, continuous); Input of other forms of energy (including electromagnetic fields, light and heat).

State change(s) in ecosystem components calling for attention/measures. The measures can be undertaken to counteract decreased abundance and size of predatory fish, negative effects that are present at a Baltic Sea wide scale.

Practical restoration method(s). Protection of shallow coastal environments by spatial or temporal closures, applying fishing gear and catch regulations, applying boating regulations, controlling seals and cormorants, etc. in order to restore populations of predatory fish.

Geographical areas in the Baltic Sea where the restoration has been tested/attempted. Measures are being discussed and attempted in many areas. For fishing regulation, see map over restricted fishing areas along the Swedish coast and offshore (se figure 1 in Bergström et al. 2016b).

Main expected responses/outcomes of the measure. The goals are to achieve invigorated populations of predatory fish, with more big individuals and the knock on effects being less eutrophication symptoms through the re-establishment of trophic control.

Evidence of success – with reference(s). Several measures can be considered, of which not all have been rigorously tested. For example, fisheries no-take areas can lead to strengthened populations of predatory fish (Egriell et al. 2007, Wikström et al. 2016, Bergström et al. 2019, Bostedt et al. 2020). Strengthened populations of predatory fish and of large individuals may relieve eutrophication symptoms and serve to strengthen habitats through re-establishment of trophic control (see e.g. Moksnes et al. 2008, Eriksson et al. 2009, Östman et al. 2016, Donadi et al. 2017, but see also Kraufvelin et al. 2020a). The measures for establishing no-take and marine protected areas are highly feasible in combination with fisheries management. The effects of permanent no-take areas are well studied, but for other measures in the Baltic Sea such as time and gear dependent regulated fishery, boating regulations, controlling seals and cormorants, etc., not much information is yet available.

Examples of ecosystem services that may be influenced positively by the measure(s). Food web dynamics, Habitat, Biodiversity, Resilience, Biological regulation, Regulation of eutrophication, Food, Recreation, Science and education, etc.

Examples of human benefits from the measure(s). Less damage from eutrophication in the society, on commercial and recreational fisheries as well as on recreation. Access to fish as food through commercial and recreational fisheries. Access to wrasses for salmon delousing in fish farms. Direct, intellectual, aesthetical and non-user values for recreation, research, education and well-being.

Target groups for the benefits in the society. Local inhabitants by the coast, professional fishermen, recreational fishermen, fish farmers, businessmen within tourism, tourists.

Possible time lags before positive effects can be seen after the measures have been undertaken. Data from Vinga marine reserve and other MPA-examples indicate that positive responses on harvestable species are detectable within 1–3 years (Egriell et al. 2007, Bergström et al. 2016, Wikström et al. 2016, Bergström et al. 2019).

Costs per unit "restored" structure or function, e.g. cost per area of habitat or weight (biomass unit) of compound. Costs for protection measures by creating no-take areas are very low. Principally they can be established more or less for free unless bought land and water areas are included or some compensation fees need to be paid to former users. However, in their analysis of benefits and costs of two temporary no-take zones, Bostedt et al. (2020) report conflicting results: when fisheries were relocated, fisheries benefits outweighed costs, but when no fisheries were relocated, costs outweighed benefits in some scenarios (Bostedt et al. 2020).

References in general. Egriell et al. 2007, Wikström et al. 2016, Bergström et al. 2016, Östman et al. 2016, Bergström et al. 2019, Kraufvelin et al.2020a, Bostedt et al. 2020.

2.9 Reducing nutrient loading by farming and harvesting blue mussels

Examples of drivers/human activities that can cause damage that needs to be restored. Not applicable.

Examples of pressures causing damage that needs to be restored. Input of nitrogen; Input of phosphorus.

State change(s) in ecosystem components calling for attention/measures. Increased eutrophication of coastal water bodies through excessive input of nutrients and organic material and high internal nutrient load in the system.

Practical restoration method(s). The measure comprises natural recruitment of blue mussels onto artificial farming substrates such as ropes (longlines) or nets hanging vertically in the water mass. This is followed by natural mussel growth and eventual harvest of mussels leading to nutrient removal (Kraufvelin & Díaz 2015, Kotta et al. 2020a).

Geographical areas in the Baltic Sea where the restoration has been tested/attempted. Farming data available from Kumlinge, Åland Islands, Finland (inner Baltic); Sankt Anna, Southeastern Sweden (central Baltic); Kiel Bay, Germany (outer Baltic); Limfjorden, Denmark; Settlement and growth data available from many areas (see Kotta et al. 2020a).

Main expected responses/outcomes of the measure. Farming and harvesting of blue mussels may lead to removal of nutrients and clearer waters. Negative environmental impacts are restricted in the case of small mussel farms and farms that are located in areas with an efficient water exchange rate (see Kraufvelin & Díaz 2015 for references), although Hedberg et al. (2018) and Wikström et al. (2020) raise concern about negative impacts in connection with big and dense farms (see below). Farming and harvesting of marine organisms is one of few methods available that are capable of direct removal of nutrients that are already present in the marine ecosystem (see also measures 9–11). Positive responses summarised: nutrient removal at harvest (one of few methods available to remove nutrients already present in the sea), clearer waters and the harvested blue mussels constitute a marine resource. Negative responses summarised: local accumulation of nutrients, organic load and possibly oxygen deficiency beneath the farm, unwanted plankton blooms, possible conflicts with boat navigation, and use of water areas at the expense of other potential activities.

Evidence of success – with reference(s). Farming and harvesting may lead to removal of nutrients and clearer waters. Farming and harvesting of marine organisms is one of the few methods available that are capable of direct removal of, but also in this case, further use of nutrients already present in the marine ecosystem (Kotta et al. 2020a, b). At the moment, the development in mussel farming for nutrient removal is fast in the Baltic Sea, especially in its south-western parts. Holbach et al. (2020) present a spatial model for the nutrient mitigation potential of blue mussel farming in the western Baltic Sea, Buer et al. (2020) reports the potential and feasibility of blue mussel farming along a salinity gradient in western Germany, whereas Taylor et al. (2019) reveal production characteristics for various methods and techniques to optimise the mitigation of eutrophication by mussel farming.

Examples of ecosystem services that may be influenced positively by the measure(s). Regulation or eutrophication, Food, Raw material, etc.

Examples of human benefits from the measure(s). Less damage from eutrophication in the society, on commercial and recreational fisheries as well as on recreation. Access to mussels as food, feed, raw material or as biomass for energy production. Improved conditions for plant and macroalgal production, swimming and recreation thanks to clearer waters. Direct, intellectual, aesthetical and non-user values for recreation, research, education and well-being.

Target groups for the benefits in the society. Local inhabitants by the coast, professional fishermen, recreational fishermen, fish farmers, mussel farmers, businessmen within tourism, tourists

Possible time lags before positive effects can be seen after the measures have been undertaken. This depends on the sites where the farming takes place, but estimates are from 6 months to 1 year before clearer waters, fewer algal blooms and lower levels of nutrients can be registered (locally). Nutrients are removed from the system in connection with harvesting and this generally takes place after 1.5 years in more saline areas (outer Baltic) and after 2.5 years in more brackish areas (central and inner Baltic).

Costs per unit "restored" structure or function, e.g. cost per area of habitat or weight (biomass unit) of compound. Information is available on the costs for removing 1 kg of nitrogen and 1 kg of phosphorus through farming and harvesting blue mussels (e.g. Lindahl 2008, 2012, Carlsson et al. 2009, Kotta et al. 2020a). The latest information by Kotta et al. (2020b) reports a cost of 38–278 euro per kg N and 924–3 854 euro per kg P.

References in general. Lindahl 2008, 2012, Carlsson et al. 2009, Isaksson 2009, Pålsson 2009, Stadmark & Conley 2011, Bergström et al. 2013, 2017, Kraufvelin & Díaz 2015, Hedberg et al. 2018, Taylor et al. 2019, Kotta et al. 2020ab, Buer et al. 2020, Holbach et al. 2020, Wikström et al. 2020, https://www.lansstyrelsen.se/kalmar/stat-och-kommun/miljo/vatten/restaurering-av-marina-miljoer.html#0.

2.10 Rehabilitation of hypoxic areas by oxygen pumping

Examples of drivers/human activities that can cause damage that needs to be restored. Not applicable.

Examples of pressures causing damage that needs to be restored. Input of nitrogen; Input of phosphorus.

State change(s) in ecosystem components calling for attention/measures. Decreased oxygen levels in sediments and bottom water.

Practical restoration method(s). Combating hypoxia through oxygen pumping has been suggested as a measure to improve the conditions of the Baltic proper and in hypoxic coastal waters (see e.g. Stigebrandt & Gustafsson 2007). The method has been tested at small scales, inner-bay-level, in Sweden and in Finland. In Byfjorden, western Sweden and in Lännerstasundet, in the inner Stockholm archipelago, there were positive short-term effects leading to decreased phosphorus levels, but in Sandöfjärden in Raseborg in Finland, there were negative results (Lehtoranta et al. 2012, Pitkänen et al. 2012, Bendtsen et al. 2013, Stigebrandt et al. 2015, Ollikainen et al. 2016).

Geographical areas in the Baltic Sea where the restoration has been tested/attempted. Byfjorden, Uddevalla, western Sweden; Lännerstasundet, inner Stockholm archipelago; Sandöfjärden, Raseborg, southern Finland.

Main expected responses/outcomes of the measure. Oxygen pumping to reoxygenate bottom waters and sediments on accumulation bottoms through artificial mixing of the water column demands hypoxia in the bottom water in order to work. The idea is that the oxygenation will prevent leakage of particle bound phosphorus to the water mass. In addition, habitats for bottom living organisms will be improved (www.havochvatten.se/download/18.b62dc9d13823fbe78c80003223/1348912824427/evaluation-box-and-proppen-projects-english.pdf). These kind of methods have, however, been criticized in the literature (e.g. Conley et al. 2009, Håkanson & Bryhn 2010, Reed et al. 2011) as they come with unknown, but potentially large risks. This restoration measure is spurious in lakes, and possibly in Baltic Sea coastal areas too, due to eutrophication leading both to oxygen deficiency and leakage of phosphorus, seemingly independently (Hupfer & Lewandowski 2008). As there always will be sediment depths with anoxic conditions, oxygenation will only lead to leakage of phosphorus a few cm deeper in the sediment.

Evidence of success – with reference(s). For the oxygen pumping in Sandöfjärden, the bottom water stayed oxygenated until the end of summer, but the pumping capacity was not sufficient to keep the entire area of 4.75 km^2 oxygenized during the entire experimental period; with oxygenized water, the P-level is low, but when oxygen drops, the P-level increases to former levels. In Lännerstasundet, which had a smaller anoxic area of 0.26 km^2, a higher pumping capacity was used and the bottom water was oxygenated within a few weeks and the P-level was significantly lower than in a reference area. Similar results have been seen from corresponding experiments in lakes (Hupfer & Lewandowski 2008). Positive long-term effects on phosphorus leakage do not occur (Pitkänen et al. 2012) and in Sandöfjärden, there was even a nitrogen release and negative end results (Ollikainen et al. 2016).

Examples of ecosystem services that may be influenced positively by the measure(s). Food web dynamics, Habitat, Biodiversity, Resilience, Regulation or eutrophication, Food, etc.

Examples of human benefits from the measure(s). Less damage from eutrophication in the society, on commercial and recreational fisheries as well as on recreation. Access to fish as food through possibly improved commercial and recreational fisheries. Direct, intellectual, aesthetical and non-user values for recreation, research, education and well-being.

Target groups for the benefits in the society. Local inhabitants by the coast, professional fishermen, recreational fishermen, fish farmers, businessmen within tourism, tourists.

Possible time lags before positive effects can be seen after the measures have been undertaken. This depends the size and volume of the water body and the hypoxic area, on water exchange rates with adjacent areas and on the intensity of the applied measure, but some positive responses may occur quite rapidly, already after a few weeks/months in bays similar to the inner bays that have been studied. Most responses are short-lived though and they are usually not kept going when the measures stop.

Costs per unit "restored" structure or function, e.g. cost per area of habitat or weight (biomass unit) of compound. For Lännerstasundet, the calculated reduction costs of nitrogen equivalents were slightly below 5 euro/kg, while the costs for reducing phosphorus equivalents were between 13–17 euro/kg (Ollikainen et al. 2016)

References in general. Stigebrandt & Gustafsson 2007, Hupfer & Lewandowski 2008, Conley et al. 2009, Håkanson & Bryhn 2010, Reed et al. 2011, Lehtoranta et al. 2012, Pitkänen et al. 2012, Bendtsen et al. 2013, Stigebrandt et al. 2015, Ollikainen et al. 2016, Stigebrandt 2018, Karlsson & Malmaeus 2018, www.naturvardsverket.se/Documents/publikationer6400/978-91-620-6522-5.pdf?pid=3831.

2.11 Reducing internal phosphorus loads by metal binding

Examples of drivers/human activities that can cause damage that needs to be restored. Not applicable.

Examples of pressures causing damage that needs to be restored. Input of phosphorus.

State change(s) in ecosystem components calling for attention/measures. Increased nutrient levels in sediments and bottom water; internal phosphorus loading.

Practical restoration method(s). Eutrophication is combated through phosphorus inactivation by addition of aluminium or iron, which has been tested at small scales, inner-bay-level, in Sweden (Malmaeus & Karlsson 2013, Huser 2014, Rydin 2014, Rydin et al. 2017, Rydin & Kumblad 2019, Kumblad & Rydin 2019).

Geographical areas in the Baltic Sea where the restoration has been tested/attempted. Björnöfjärden, Stockholm archipelago, eastern Sweden; Granfjärden, Östhammar, eastern Sweden.

Main expected responses/outcomes of the measure. Metal treatment of active sediments (accumulation bottoms) prevents leakage of phosphorus by binding P in particle form instead of leaking out into the water as phosphate ions (Huser 2014, Rydin 2014, Rydin et al. 2017). This method has been tested in Björnöfjärden with aluminium (Malmaeus & Karlsson 2013, Rydin et al. 2017) and in Östhammarsfjärden with iron (Rydin 2014) in eastern Sweden. These kind of methods have, however, been criticized in the literature (e.g. Conley et al. 2009, Håkanson & Bryhn 2010, Reed et al. 2011).

Evidence of success – with reference(s). Rydin et al. (2017) evaluated the tests using aluminium in Björnöfjärden and they demonstrated lowered phosphorus levels in the water as well as an increased water clarity.

Examples of ecosystem services that may be influenced positively by the measure(s). Food web dynamics, Habitat, Biodiversity, Resilience, Regulation or eutrophication, Food, etc.

Examples of human benefits from the measure(s). Less damage from eutrophication in the society, on commercial and recreational fisheries as well as on recreation. Access to fish as food through possibly improved commercial and recreational fisheries. Direct, intellectual, aesthetical and non-user values for recreation, research, education and well-being.

Target groups for the benefits in the society. Local inhabitants by the coast, professional fishermen, recreational fishermen, fish farmers, businessmen within tourism, tourists.

Possible time lags before positive effects can be seen after the measures have been undertaken. The time needed for recovery depends the size and volume of the water body, water exchange rates and the intensity of the applied measure, but some positive responses may occur quite rapidly, already after a few weeks/months in inner bays. Most responses are short-lived though and they are usually not sustained when the measures stop.

Costs per unit "restored" structure or function, e.g. cost per area of habitat or weight (biomass unit) of compound. Rydin (2014) calculated an aluminium cost of 10 euro per kg phosphorus bound to aluminium in the sediment, without application costs, by this method. The total costs for aluminium treatment of Björnöfjärden is calculated to 900 000 euro. In total, it is expected that 4 tonnes of phosphorus can be bound to added aluminium. This corresponds to the entire phosphorus surplus (the “old sins”) in Björnöfjärden. When 4 tonnes of phosphorus is bound, the cost for the measure becomes 225 euro/kg P (Kumblad & Rydin 2019). Håkanson & Bryhn

(2010) commented in their criticism that it would be more cost-effective to remove phosphorus in land-based water treatment plants. For removal of phosphorus water treatment plants, Hasselström (2007) presents a cost range of 42–108 euro/kg P.

References in general. Hasselström 2007, Conley et al. 2009, Håkanson & Bryhn 2010, Reed et al. 2011, Malmaeus & Karlsson 2013, Huser 2014, Rydin 2014, Rydin et al. 2017, Rydin & Kumblad 2019, Kumblad & Rydin 2019.

2.12 Investigative and trial biomanipulation by removing cyprinids and sticklebacks as a method for rehabilitating coastal ecosystems

Examples of drivers/human activities that can cause damage that needs to be restored. Not applicable.

Examples of pressures causing damage that needs to be restored. Extraction of target fish and shellfish species and incidental fish catches; Changes to hydrological conditions; Input of nitrogen; Input of phosphorus.

State change(s) in ecosystem components calling for attention/measures. Decreased numbers of predatory fish, excessive nutrient levels.

Practical restoration method(s). Biomanipulation through fisheries targeting mesopredators as cyprinids or sticklebacks aims at re-establishing or affecting trophic structures in ecosystems where these have been altered. The alterations may for example be due to overfishing of large predatory fish, eutrophication or conditions otherwise becoming more beneficial for mesopredators and leading to a dominance of mesopredators (i.e. small predators in the food web) such as cyprinids, stickle-back and black goby in the Baltic Sea and wrasses and shore crabs in Kattegat. The measure can also be undertaken to reduce the amount of nutrients. Biomanipulation of planktivorous fish has been tested as a restoration method in lakes (Hansson et al. 1998, Lammens 2001, Mehner et al. 2004), but biomanipulation is a relatively untested measure in marine systems (but see Jokinen & Reinikainen 2011, Sandström 2011, https://johnnurmisensaatio.fi/en/projects/local-fishing-project/). On a more general level, enhancing trophic regulation in coastal fish populations has been suggested as a potential measure for essential seagrass and seaweed areas of the Baltic Sea (Östman et al. 2016).

Geographical areas in the Baltic Sea where the restoration has been tested/attempted. Pickala Bay, Gulf of Finland and the Archipelago Sea, southern Finland for testing biomanipulation of cyprinids; Åland (Finland), Gulf of Bothnia and Småland and Östergötland (Sweden) for testing biomanipulation of sticklebacks.

Main expected responses/outcomes of the measure. Under the right circumstances, the measure could contribute to the re-establishment of top-down control by predatory fishes as well as removal of nutrients already present in the system (by removing mesopredatory fish from the system by fishing).

Biomanipulation measures could be undertaken to counteract increased eutrophication symptoms and problems with trophic cascade effects (Östman et al.

2016). Biomanipulation of sticklebacks (http://balticsea2020.org/alla-projekt/rovfisken/12-rovfisken-pagaende-projekt/464-trala-efter-storspigg-i-bottenviken), for instance, could provide positive effects both through the trophic regulation of filamentous algae and decreased stickleback predation on the egg and larvae of predatory fish, although this has not been tested (Byström et al. 2015, Bergström et al. 2015). Biomanipulation aiming at cyprinids is another alternative which has been tested in Finland without much reported success with regard to a decrease in total biomass of bream nor as improved water quality (Jokinen & Reinikainen 2011). It has also been tested in Sweden (Sandström 2011). See also https://johnnurmisensaatio.fi/en/projects/local-fishing-project/ for more successful initiatives).

Evidence of success – with reference(s). As biomanipulation of ecosystems is very complicated with high risk of failures, the effects and possible successes are hard to judge beforehand. Therefore, methods for biomanipulation, if they are considered relevant, should first be tested at a small local scale. A positive side-effect of targeted biomanipulation would be that nitrogen and phosphorus also are removed from the ecosystem together with the caught fish (Hjerne & Hansson 2002). Biomanipulation is, together with farming and harvesting of marine organisms and binding phosphorus by aluminium and iron, one of the few methods available that are capable of direct removal of nutrients already present in the marine ecosystem.

The proposed measures include references to a few studies of trials in archipelagos of the northern Baltic Proper. The measure is probably feasible only at small and highly controlled scales. There is still a lack of knowledge of effects and high risks of failures and therefore needs for replicating trials to study wider ecosystem effects in order to determine where and when the methods could be most appropriate.

The measure should initially focus on further trials and investigations, but not be used for full scale implementation at this stage. The effects of the measure are still relatively unknown in coastal areas and the results may be very site-specific. The measure should also include consideration of how the captured fish is utilised in the best way in order to avoid a waste of natural resources.

Examples of ecosystem services that may be influenced positively by the measure(s). Food web dynamics, Biodiversity, Resilience, Biological regulation, Regulation of eutrophication, Food, Recreation, Science and education, etc.

Examples of human benefits from the measure(s). Less damage from eutrophication in the society, on commercial and recreational fisheries as well as on recreation. Access to fish as food through commercial and recreational fisheries. Access to wrasses for salmon delousing in fish farms. Direct, intellectual, aesthetical and non-user values for recreation, research, education and well-being.

Target groups for the benefits in the society. Local inhabitants by the coast, professional fishermen, recreational fishermen, fish farmers, businessmen within tourism, tourists.

Possible time lags before positive effects can be seen after the measures have been undertaken. There seems to be a lack of information about time lags for the effects of biomanipulation of coastal fish.

Costs per unit "restored" structure or function, e.g. cost per area of habitat or weight (biomass unit) of compound. There is a general lack of details with regard to biomanipulation costs for Baltic Sea fish, but Sandström (2011) reported a cost of 160 euro per kg P in their biomanipulation study of cyprinid fishing in Östhammar, eastern Sweden. For cyprinid fishing in the Archipelago Sea in Finland, it is estimated that 8 tonnes of phosphorus can be recycled from the sea on a yearly basis (https://johnnurmisensaatio.fi/en/projects/local-fishing-project/). This latter cyprinid fishing is also self-sustaining at the moment, i.e. the phosphorus reduction takes place for free as it results in a food product that is consumed by humans. All that was needed to get this going was some initial efforts to achieve a useful product and then find a market for it.

References in general. Hansson et al. 1998, Lammens 2001, Hjerne & Hansson 2002, Mehner et al. 2004, Søndergaard et al. 2008, Jokinen & Reinikainen 2011, Jeppesen et al. 2012, Byström et al. 2015, Bergström et al. 2015, Östman et al. 2016, Iho et al. 2017, http://balticsea2020.org/alla-projekt/rovfisken/12-rovfisken-pagaende-projekt/464-trala-efter-storspigg-i-bottenviken, https://seabasedmeasures.eu/pilots/.

2.13 Rehabilitation of anoxic, nutrient rich or polluted sediments by removal or coverage

Examples of drivers/human activities that can cause damage that needs to be restored. Fish and shellfish processing; Aquaculture – marine, including infrastructure; Transport – shipping infrastructure (harbours, ports, ship-building); Industrial uses (oil, gas, industrial plants); Waste waters (urban, industrial, and industrial animal farms); Solid waste (land-based disposal of dredged material and, e.g. land-fill); Tourism and leisure infrastructure (piers, marinas); Tourism and leisure activities (boating, beach use, water sports, etc.).

Examples of pressures causing damage that needs to be restored. Changes to hydrological conditions; Input of nitrogen; Input of phosphorus; Input of organic matter — diffuse sources and point sources; Input of other substances (e.g. synthetic substances, non-synthetic substances, radionuclides) — diffuse sources, point sources, atmospheric deposition, acute events; Input of litter (solid waste matter, including micro-sized litter).

State change(s) in ecosystem components calling for attention/measures. Dead or disturbed sediments due to hypoxia, nutrient enrichment or pollution.

Practical restoration method(s). Removal of sediment through various methods of careful dredging and/or coverage of damaged soft bottoms with a clean substrate or active carbon can lower the environmental effects from toxic compounds in polluted sediments, e.g. in harbours, marinas or in industrial recipients (Akcil et al. 2015, Rostmark et al. 2015, Eriksson et al. 2016). Similar methods could possibly be used for removal of anoxic or nutrient rich sediments for example in shallow bays in order to combat macroalgal mats (Hulth & Sundbäck 2009).

Geographical areas in the Baltic Sea where the restoration has been tested/attempted. Harbour areas, recipient outside forest industries (e.g. in the Gulf of Bothnia).

Main expected responses/outcomes of the measure. Recolonization of plants (in the photic zone) and animals (in the photic and aphotic zone) are typical positive responses in rehabilitated areas. If the surface sediment is removed or altered, however, a biogeochemically active layer with associated functions disappear with possible consequences for the recovery (Hulth & Sundbäck 2009). Experiments have shown that lower levels of bottom living microalgae restrict the recolonization of macrofauna (Stocks & Grassle 2001).

Evidence of success – with reference(s). Full recovery after measures such as dredging or cover is probably restricted both by a slow or seasonal recruitment and by the availability of food (see Norkko et al. 2006 for references). The spatial scale of the disturbance seems to be the most crucial factor for the speed, succession and completeness of the recolonising macrofauna community (Lewis et al. 2002, Bolam et al. 2006, Norkko et al. 2006). The recovery of flora and fauna can possibly be boosted by leaving undisturbed refugia in the treated area that can serve as local banks for a recolonization (Hulth & Sundbäck 2009).

Removal measures include risks to release bound nutrients and pollutants, which can increase eutrophication and damage to the environment and be counter-productive to conservation efforts.

Some literature from freshwater systems (lakes) can be used to better identify pros and cons of the different measures.

Many of these measures are quite expensive, but they could be included as mandatory measures or as compensation restoration in cases when the polluter is known or activities are being permitted/planned.

More research is needed. Background material is mainly available about the recovery of unvegetated soft bottoms following active measures or naturally.

Examples of ecosystem services that may be influenced positively by the measure(s). Biogeochemical cycling, Primary production, Food web dynamics, Habitat, Biodiversity, Resilience, Regulation of eutrophication, Food, Raw material, Science and education, etc.

Examples of human benefits from the measure(s). Less damage from eutrophication in the society, on commercial and recreational fisheries as well as on recreation. Access to fish as food through commercial and recreational fisheries. Direct, intellectual, aesthetical and non-user values for recreation, research, education and well-being.

Target groups for the benefits in the society. Local inhabitants by the coast, professional fishermen, recreational fishermen, fish farmers, businessmen within tourism, tourists.

Possible time lags before positive effects can be seen after the measures have been undertaken. Positive responses for the macrofauna occur quite rapidly during summer seasons, i.e. within weeks and months (Lewis et al. 2002).

Costs per unit "restored" structure or function, e.g. cost per area of habitat or weight (biomass unit) of compound. Wasserman et al. (2013) estimated costs around 22 euro per dredged m^3 of polluted sediment and 14 euro per dumped m^3 (Rio de Janeiro, Brazil).

References in general. Stocks & Grassle 2001, Lewis et al. 2002, Bolam et al. 2006, Norkko et al. 2006, Hulth & Sundbäck 2009, Apler & Nyberg 2011, Cooper et al. 2013, Nyberg et al. 2013, Apler et al. 2014, Wasserman et al. 2016, Akcil et al. 2015, Rostmark et al. 2015, Eriksson et al. 2016, Zhang et al. 2016.

2.14 Establishment of artificial reefs

Examples of drivers/human activities that can cause damage that needs to be restored. Restructuring of seabed morphology (dredging, beach replenishment, sea-based deposit of dredged material); Extraction of minerals (rock, metal ores, gravel, sand, shell).

Examples of pressures causing damage that needs to be restored. Physical disturbance to seabed (temporary or reversible and recovers within 12 y); Physical loss (due to permanent change of seabed substrate or morphology and to extraction of seabed substrate); Changes to hydrological conditions.

State change(s) in ecosystem components calling for attention/measures. Loss of hard surfaces through exploitation, stone fishing, marine extraction.

Practical restoration method(s). Establishing artificial reefs/substrates to allow for colonisation of hard bottom macroalgal and macrofaunal assemblages including crustaceans, mussels and fish. The reefs may be deployed intentionally as active measures (Bohnsack & Sutherland 1985, Baine 2001, Jensen 2002, Seaman 2007, Fabi et al. 2011) or un-intentionally, for example as ship wrecks in connection with accidents (Ruuskanen et al. 2015, Balazy et al. 2019). The difference from restoration of stone reefs is that the artificial reefs are not used for dealing with historical losses, but rather for adding new structures to the underwater seascape. Artificial reefs are controversial and should be used with caution.

Geographical areas in the Baltic Sea where the restoration has been tested/attempted. In Kiel and in Nienhagen, northern Germany; in the Odra river estuary, in Puck Bay and in the Pomeranian Bay, Poland; in the Vistula Lagoon, Russia; in the Gulf of Riga, Estonia; in the Gulf of Finland, Russia and Finland (Fabi et al. 2011).

Main expected responses/outcomes of the measure. Artificial reefs may have positive impact, but mainly locally, within coastal areas. The measure is only to be considered for areas with historical loss of the substrate that the reef mimics. Positive responses summarised: more habitat/substrates for marine organisms especially fish and shellfish, increased biodiversity, preserved ecosystem services. Negative responses summarised: altered bottom structure, impact on water circulation, effects on soft bottom organisms and that the new habitat may demand space from other marine habitats. Introduced hard substrates in areas of predominating soft bottoms can also serve as stepping stones for non-indigenous invasive species. Promoting "attraction by individuals" ahead of "production" can lead to overharvesting of fish unless fisheries are also managed as it is unclear whether the measure simply aggregates organisms to reefs rather than increasing the biomass. Negative impact on existing values should be weighed against the expected ecological improvements beforehand when planning to establish artificial reefs.

In Denmark there are guidelines that strongly advise against restoration using artificial structures and it is preferred to restore reefs with stones, in areas where stones have earlier been removed. There is, however, one project with the sunken ferry Ærø that isused as an artificial reef. https://blog.divessi.com/return-to-denmarks-aerosund-sunken-ferry-has-become-thriving-artificial-reef-1748.html.

In Sweden, reefs are currently being tested in order to support cod (https://www.slu.se/ew-nyheter/2020/5/slu-utvarderar-om-konstgjorda-rev-kan-radda-torsken/).

Evidence of success – with reference(s). Artificial reefs attract e.g. fish and shellfish and they are of interest both for commercial and recreational fisheries and for recreation (Seaman 2007, Fabi et al. 2011), although they can also affect the benthic environments negatively (Bulleri & Chapman 2010, Dafforn et al. 2015, Ruuskanen et al. 2015).

The measure is feasible but the use of artificial reefs may be disputed ethically and environmentally. Probably, there will mainly be positive effects at the local scale. Preferably, only natural material should be used.

Examples of ecosystem services that may be influenced positively by the measure(s). Food web dynamics, Habitat, Biodiversity, Resilience, Climate and atmospheric regulation, Sediment retention, Recreation, Science and education, etc.

Examples of human benefits from the measure(s). Less physical damage on shores, properties and infrastructure. Access to macroalgae, mussels and oysters as raw material, food and feed. Access to fish as food through commercial and recreational fisheries. Access to wrasses for salmon delousing in fish farms. Direct, intellectual, aesthetical and non-user values for recreation, research, education and well-being.

Target groups for the benefits in the society. Local inhabitants by the coast, professional fishermen, recreational fishermen, fish farmers, businessmen within tourism, tourists.

Possible time lags before positive effects can be seen after the measures have been undertaken. The time needed for positive effects to occur are probably similar to the case with stony/boulder reefs, i.e. within weeks/months for macroalgae and small macroinvertebrates and ca 2–3 years for lobster and fish (Egriell et al. 2007, Wikström et al. 2016).

Costs per unit "restored" structure or function, e.g. cost per area of habitat or weight (biomass unit) of compound. Costs are highly variable, ranging from almost nothing (zero costs) to more than 100 000 euro, mostly depending on the type of structures and measures, technique, whether monitoring is included, etc.

References in general. Buckley 1982, Russell et al. 1983, Bohnsack & Sutherland 1985, Grove et al. 1989, Milon 1989, Baine 2001, Svane & Petersen 2001, Reed et al. 2002, Deysher et al. 2002, Jensen 2002, Christie 2005a, b, 2007, Wilhelmsson et al. 2006, Egriell et al. 2007, Seaman 2007, Wilhelmsson & Malm 2008, Isaksson 2009, OSPAR COMMISSION 2009, Pålsson 2009, Christie & Fredriksen 2011, Fabi et al. 2011, Pioch et al. 2011, Perkol-Finkel et al. 2012, Claisse et al. 2014, Firth et al. 2014, Dafforn et al. 2015, Ponti et al. 2015, Rouanet et al. 2015, Ruuskanen et al. 2015, Zeffer 2015, Ferrario et al. 2016, López et al. 2016, Schroeter et al. 2016, Silva et al. 2016, Smith et al. 2016, Ushiama et al. 2016, 2019, Walles et al. 2016, Wikström et al. 2016, Balazy et al. 2019, www.naturstyrelsen.dk/naturbeskyttelse/naturprojekter/blue-reef/, www.riff-nienhagen.de/index_en.shtml.

2.15 Protection of habitats

Examples of drivers/human activities that can cause damage that needs to be restored. This refers to past activities leading to loss of functions such as natural habitats. Land claim; Canalisation and other watercourse modifications (coastal dams, culverting, trenching, weirs, large-scale water deviation); Coastal defence and flood protection (seawalls, flood protection); Restructuring of seabed morphology (dredging, beach replenishment, sea-based deposit of dredged material); Fish and shellfish harvesting (bottom-touching towed gears, professional, recreational); Fish and shellfish harvesting (pelagic towed gears, stationary gears, professional, recreational); Aquaculture – marine, including infrastructure; Transport – shipping (incl. anchoring, mooring); Transport – shipping infrastructure (harbours, ports, ship-building); Urban uses (land use); Tourism and leisure infrastructure (piers, marinas); Tourism and leisure activities (boating, beach use, water sports, etc.).

Examples of pressures causing damage that needs to be restored. Loss of, or change to, natural biological communities due to cultivation of animal or plant species; Disturbance of species: Visual, presence, boating, recreational activities, above-water noise; Disturbance of species: Other (e.g. barriers, collision); Extraction of target fish and shellfish species and incidental fish catches; Physical disturbance to seabed (temporary or reversible and recovers within 12 y); Physical loss (due to permanent change of seabed substrate or morphology and to extraction of seabed substrate); Changes to hydrological conditions; Input of organic matter — diffuse sources and point sources; Input of anthropogenic sound (impulsive, continuous); Input of other forms of energy (including electromagnetic fields, light and heat).

State change(s) in ecosystem components calling for attention/measures. Habitat degradation is continuously increasing in coastal areas today, since the effect of physical modifications of the seabed, tourism and boating activities, etc. lead to cumulative loss of habitat. Thus, the measure is relevant in all parts of the Baltic Sea coastline.

Practical restoration method(s). Habitat protection by establishing marine protected areas (MPAs), protection of shallow coastal environments and shore protection, applying fishing and boating regulations. Measures in the coastal zone can preferably be done in combination with measures to protect open sea areas in the Baltic Sea.

Geographical areas in the Baltic Sea where the restoration has been tested/attempted. A map showing MPAs in the Baltic Sea as well as their management plan status can be found at: https://helcom.fi/action-areas/marine-protected-areas/management-of-helcom-mpas/. From this map, it can be seen that MPAs are present in a representative way in all sub-basins and in all coastal nations of the Baltic Sea.

Main expected responses/outcomes of the measure. Safeguarding important habitats for the maintenance of biodiversity and provision of ecosystem services, for example the recruitment and production of fish (Sundblad et al. 2014, Kraufvelin et al. 2018), can be considerably more effective compared to restoration of deteriorated habitats. This is true in terms of cost efficiency and since there is usually no time lag before the effect of the implementation can be seen. In comparison, restoration is likely to require more resources in terms of cost and time and a has a lower level of certainty in that all original functions and ecosystem services will be recovered. Habitat protection is expected to work absolutely best in combination with other restoration measures. It seems, however, that there are huge differences in the perception of what is protected between countries with regard to MPAs. In some areas, there are many restrictions in the uses of the protected areas and they can more or less be seen as no-take areas, while in other areas, almost anything can be done with the possible exception of establishing industries. This is also in line with the conclusions from the work on marine protected areas in the WP3 of the HELCOM ACTION project (HELCOM 2021).

Evidence of success – with reference(s). There is generally a lack of follow-up studies on the effect of habitat protection in the Baltic Sea. However, substantial indirect evidence is provided from studies showing how habitat deterioration reduces fish productivity (Kraufvelin et al. 2018). For example, Sundblad et al. (2014) showed that habitat limitation for early life stages of perch and pikeperch may restrict the abundance of later adult stage fish. There is evidence of long-term negative effects on fish reproduction habitats from physical development, boating and infrastructure related to boating (Sandström et al. 2005, Sundblad & Bergström 2014, Hansen et al. 2018, Sagerman et al. 2020), and studies have shown negative impacts on the habitat and the production of juvenile fish from recreational boating traffic (Sandström et al. 2005). These studies are from Swedish waters but the observed relationships can be assumed to also apply to other countries in the Baltic Sea.

The positive impacts are mainly local, within coastal areas, but with a potential for positive basin-wide effects (e.g. through serving as spawning areas with spill-over effects).

Although the effects of marine protected areas are quite well studied, there is generally a lack of follow-up studies on the effect of habitat protection in the Baltic Sea.

Examples of ecosystem services that may be influenced positively by the measure(s). Food web dynamics, Habitat, Biodiversity, Resilience, Biological regulation, Regulation of eutrophication, Food (as spillover), Recreation, Science and education, etc.

Examples of human benefits from the measure(s). Less habitat damage from coastal development and improved recreation. There may also be possible improvements in commercial and recreational fisheries. Direct, intellectual, aesthetical and non-user values for recreation, research, education and well-being.

Target groups for the benefits in the society. Local inhabitants by the coast, professional fishermen, recreational fishermen, fish farmers, businessmen within tourism, tourists.

Possible time lags before positive effects can be seen after the measures have been undertaken. Data from Vinga marine reserve (habitat protection in combination with establishment of stony reefs) and other MPA-examples indicate that positive responses on harvestable species are detectable within 1–3 years (Egriell et al. 2007, Bergström et al. 2016, Wikström et al. 2016, Bergström et al. 2019).

Costs per unit "restored" structure or function, e.g. cost per area of habitat or weight (biomass unit) of compound. Costs for protection measures by creating marine reserves are very low, but depending on the inclusion of follow-up measures, monitoring and enforcements (HELCOM 2021). Principally they can be established more or less for free unless bought land and water areas are included or some compensation fees need to be paid to former users. However, in their analysis of benefits and costs of two temporary no-take zones, Bostedt et al. (2020) got conflicting results: when fisheries were relocated, fisheries benefits outweighed costs, but when no fisheries assumingly were relocated, costs outweighed benefits in some scenarios.

References in general. Sandström et al. 2005, Egriell et al. 2007, Sundblad & Bergström 2014, Sundblad et al. 2014, Wikström et al. 2016, Bergström et al. 2016, Hansen et al. 2018, Kraufvelin et al. 2018, Bergström et al. 2019, Bostedt et al. 2020, Sagerman et al. 2020.

2.16 Follow-up and knowledge sharing

Description of measure. This measure aims to enhance the evidence-base for the efficiency of measures over time by mutual sharing of existing and ongoing experiences among countries. To support an adaptive management, it might also be beneficial to apply measures as tests with the dual aim of improving environmental status and learning. The measure "Follow-up and knowledge sharing" is further expected to support engagement and acceptance to measures among the general public and stakeholders concerning the needs of the measures and their objectives, if supported by campaigns dedicated for specific groups.

Effectiveness of measure. Even though a wide range of measures has already been implemented for habitats in the Baltic Sea, there is generally a lack of scientific evaluations and evidence on the effects of many of the measures. Scientific evidence to follow-up on the effectiveness of measures for coastal habitats is only available for a few measures and for some areas. This lack of knowledge significantly limits the work with restoring and supporting coastal habitats through impacts on the capacity of society to carry out measures. An effective way to support an increased evidence base would be to encourage adaptive learning and the mutual sharing of experiences among countries. To gain stronger support for these measures and for those not yet suggested in this report, it is of outmost importance that past, on-going and future measures for coastal habitats are scientifically evaluated, something that unfortunately is undertaken only rarely today. Designed in a proper manner and applied for a specific coastal area, many measures to improve coastal habitats are likely to have positive effects on other parts of the food web, as well.

3. Estimating the efficiency of different measures related to restoration of coastal habitats

3.1 General aspects on estimating the efficiency

Based on available examples, the recovery of coastal ecosystems is often a slow process that extends over several decades (Kraufvelin et al. 2001, Duarte et al. 2009, 2015, 2020, Borja et al. 2010, Lotze et al. 2011, Verdonschot et al. 2013). Duarte et al. (2020) present an average recovery time of 20 years for global marine ecosystems and specific ranges of 1–5 years for oyster reefs, 2–30 years for exploited invertebrates, 5–60 years for seagrasses, 10–30 years for exploited fish and 40–60 years for whales to give a few examples. Even with recoveries being reached, the resulting ecosystem can in many cases only approximate, but not fully replicate, what has been lost (Elliott et al. 2007). Due to the difficulties in re-establishing true historic conditions, we may thus more often have to focus on restoring ecosystem functions and become better at integrating such initiatives into restoration ecology (Kollmann et al. 2016).

Jones & Schmitz (2009) compiled a broad review over required time scales for terrestrial and aquatic biological recovery and demonstrate recovery times of on average 10–20 years for brackish and marine systems. In their review, Jones & Schmitz (2009) also acknowledge that information about pre-disturbance conditions was only available in 20% of the studied cases, which makes recovery judgement biased in 80% of the cases. Scientific studies showing the entire long-term degradation of ecological structures and functions are also rare in the literature and so are studies that can provide us with extensive descriptions about mechanisms for the recovery of different systems (Jones & Schmitz 2009). Studies presenting long-term monitoring data covering several trophic levels (such as plankton, benthic organisms and fish, etc.) together with physical and chemical water and sediment variables are also very rare (Simenstad et al. 2006, Lotze et al. 2006, Elliott et al. 2007, 2016, Jones & Schmitz 2009). Such level of detail would be valuable for demonstrating recovery processes after marine restoration measures. In this context, it is also important to be explicitly clear in what we mean with restoration, i.e. is it to an original state or to a more approximate state with acceptable ecological functions (Duarte et al. 2009, 2015)?

Even though the recovery of certain biological communities can occur in less than five years, a full recovery of many marine systems often requires at least 15–25 years (Duarte et al. 2020). A re-establishment of the original biological species composition, biodiversity and ecological function can take even longer, maybe up to 50 years (Borja et al. 2010). Some ecosystems may never reach the technical definition of being restored, but may instead proceed irreversibly to an alternative state (Scheffer et al. 2001, Duarte et al. 2009, 2015, Borja et al. 2010). Ecosystem structure can in many cases recover and the former species can be present, but this does not have to mean that the former ecosystem function has been re-established, too. In situations when restoration measures are undertaken rapidly and natural processes are recovering completely, significant improvement in ecological conditions may be achieved within 15–25 years, even though the original historical conditions not necessarily are reached (Hering et al. 2010). Regarding recovery times, it is also crucial to consider the role of water exchange rates in different ”basins” or water areas, since this has a great influence on how marine systems are developing. We also need to establish whether dynamic marine systems, with very variable hydrodynamics, recover faster than less dynamic low energy systems (Borja et al. 2010).

In every restoration case, it is important right from the start to agree upon the aims/objectives and which criteria to be used to assess how well these have been met afterwards (Simenstad et al. 2006, Seaman 2007, Borja et al. 2010). It must also be addressed whether the restored system rather contains its structural elements, i.e. the relevant species composition, or if a fully functioning system with the right levels of primary producers, predator prey relationships and other species interactions, etc. has been recreated.

3.2 Scoring

The selection of measures presented in chapter 2 is aligned with a Swedish national report by Kraufvelin et al. (2020b), where various existing and implemented restoration measures in the Baltic Sea and in nearby areas have been evaluated, and expanded within the HELCOM ACTION project. The different measures have been described and evaluated using scores with respect to various aspects that address their feasibility and/or effectiveness (using scores 1–3 or 0–3, the higher, the better). The following aspects/criteria were used:

- The type of measure, going from measures with higher chances of re-creating historical (pristine) conditions to measures with lower chances (i.e. “restoration”, “rehabilitation”, “assisted natural recovery”, “habitat improvement”, “enhancement”, “replacement”, “mitigation” and “other measures”),
- If the restoration targets represent “threatened species/habitats”,
- If the restoration targets represent “important ecosystem services/human benefits”,
- If there are “potential risks of taking no action” with regard to the restoration target,
- If the focus of the measure is on “causes”, “symptoms” or “both”,
- The availability of methodology,
- The existence of relevant practical experiences,
- The chances for long-term attainment of the result,
- The needs for complementary measures to achieve the aims,
- The risks of negative side-effects from the measures,
- The size (spatial scale) of the area that may be affected positively,
- Draft evaluation of the costs to achieve the measures.

As part of the HELCOM ACTION workshop in February 2020 (HELCOM ACTION WS2.2-2020), seven participating benthic experts from across the region got a chance to fill in a "score card" based on the above aspects. In addition, the score card has been filled in by the five authors of this report. The obtained averaged scores of these 12 experts, for each combination of aspect and restoration measure were summed up to give an overall estimate (for detailed results for individual criteria, see Appendix 1). Within this process, a value for "certainty" was obtained by the standard deviations from the given scores (for detailed results for individual criteria, see Appendix 2). Also, on the basis of this exercise, total averages and averaged SDs have been summed-up for all measures and the measures were ranked by their tallied totals and ordered in Table 1 from those with the highest total sum to those with the lowest total sum in the first column and averaged variability in the scores in the second column. Here, it must be noted that these Appendices and Table 1 do not represent any absolute truths about which restoration measures that are most feasible and efficient, but only the expert's view on the topic.

Table 1. Results of an expert evaluation of the feasibility/effectiveness of different restoration measures in the Baltic Sea using 12 experts (see text) who got the chance to fill in a "score card" and then averaged scores were calculated for each combination of aspect and restoration measure and summed up and also a value for "certainty" by simply using standard deviations from the scores given. Green shades indicate the more feasible measures (i.e. high average scores) as well as the highest levels of agreement (i.e. low standard deviation) and red shades indicate the opposite.

Restoration measure **(The numbering follows Chapter 2, where each measure is presented in more detail)**	Average tallied sums of eight experts	Averaged SDs indicating agreement among the experts (lower value means more agreement)
7. Restoration of coastal wetlands and fladas/lagoons	31,2	0,45
15. Protection of habitats	30,1	0,54
5. Restoration of stony reefs	26,3	0,57
4. Restoration of blue mussel reefs	25,7	0,59
8. Invigorating piscivorous fish populations to rehabilitate coastal ecosystem function	25,6	0,75
1. Restoration of eelgrass, *Zostera marina*	24,5	0,42
2. Restoration of soft bottom macrophytes (other than eelgrass)	23,3	0,55
3. Restoration of brown macroalgae, mainly *Fucus vesiculosus*	23,1	0,42
14. Rehabilitation of hard bottoms by establishment of artificial reefs	21,7	0,64
9. Reducing nutrient loading by farming and harvesting blue mussels	19,8	0,69
13. Rehabilitation of anoxic, nutrient rich or polluted sediments by removal or coverage	19,5	0,65
6. Restoration of soft bottoms naturally free of vegetation	19,3	0,7
12. Biomanipulation to remove cyprinids and sticklebacks and rehabilitate coastal ecosystem function	19,2	0,65
11. Reducing internal phosphorus loads by metal binding	18,5	0,62
10. Rehabilitation of hypoxic areas by oxygen pumping	15,8	0,5

According to the summed up values in this exercise, measures such as restoration of coastal wetlands and protection of habitats rank at the highest end (most feasible/effective), whereas many traditional habitat restoration measures are considered less feasible/effective (found in the middle of the table). Some rehabilitating and physico-chemical measures are ranked the lowest (Table 1). The highest agreement among experts was registered for the restoration of coastal wetlands, restoration of eelgrass meadows and restoration of brown macroalgae, whereas the least agreement was found for measures strengthening piscivorous fish, for restoration of soft bottoms naturally free of vegetation and for using mussel farming for nutrient harvesting and reducing nutrient loads (Table 1).

4. Identification of prioritized restoration measures for different parts of the Baltic Sea

All measures are likely not equally effective in all geographical areas. Depending on local community composition and key species, the physical habitat characteristics as well as identified key impacts and pressures, different restoration measures may be advisable in different geographical areas. It is noteworthy here that these spatial differences between areas are very important to consider and will likely affect the choice of, but also the success of, the measures locally, regionally and at the Baltic Sea-wide scale (i..e when regional experts completed the questionnaire). This is because different measures are relevant and work differently in various parts of the Baltic Sea as a result of strong hydromorphological, chemical, physical and biological gradients (Leppäkoski & Bonsdorff 1989). Other differences are present in human population density and also in how land and water areas are used and exploited (Kraufvelin et al. 2020c). In addition to this, there may also be significant local variations between nearby areas, for example with regard to freshwater inflow, nutrient load and degree of wave exposure (Bryhn et al. 2017b).

Moreover, pressures are often acting cumulatively on habitats both within and among pressure types and thus, the use of multiple restoration measures at the same time is foreseen to be more efficient than applying just one measure alone. A combined restoration of eelgrass beds with blue mussel reefs could exemplify a case capable of presenting possible positive synergies. Restoration of eelgrass could benefit from a higher biomass of filter-feeders locally as these keep the waters clearer (Coen & Luckenbach 2000, Coen et al. 2007, Sharma et al. 2016). Similar positive synergy effects could possibly also be achieved for benthic macrophytes through mussel farming (Kraufvelin & Díaz 2015).

Based on different sources of information available such as the HELCOM Baltic Sea Impact index, the Swedish SYMPHONY-tool, other projects, etc. and local and regional expert knowledge, this work also intends to map and present which habitats and areas in the Baltic Sea are the most damaged and where different types of restoration measures should be of the highest significance/need. The ultimate aim of this chapter of the report is to suggest viable and cost-effective restoration measures to these habitats/areas, and provide recommendations for specific measures needed to restore them.

For these purposes, a questionnaire (Table 2) was distributed among experts within different HELCOM working groups during 2019–2020. Unfortunately, these attempts rendered only one reply. This part of the work thus needs to be revised and repeated later on.

In the lack of input from experts about where restoration measures would be of highest significance/need, evaluations for this report will instead primarily be based on:

- existing knowledge of activities and pressures in the Baltic Sea area such as from the HELCOM ACTION WP 2.1-report, compiled in parallel to this report,
- existing information about the distribution and condition of ecosystem components from Korpinen et al. (2012) and HELCOM (2018) and published literature such as the

review paper by Kraufvelin et al. (2018) about essential fish habitats, which also include relevant information for this purpose,
- existing knowledge from national underwater mapping activities and evaluations (such as the underwater habitat mapping undertaken in Finland and Sweden).

Table 2. Questionnaire to define in which coastal areas of the Baltic Sea the restoration measures are of highest significance/need.

Restoration targets/methods	**Guidance**	**1–15. Separate columns for all the different restoration measures**
Is this measure to your knowledge already in use in your country/area/sub-basin?	Yes, no, ?	
Estimate the level of relevance/need for the measure in your country/area/sub-basin?	3 = high; 2 = medium; 1 = low; 0 = no	
Your view of the cost-effectiveness of the measure in your country/area/sub-basin?	3 = high; 2 = medium; 1 = low; 0 = no	
In which countries/areas/sub-basins do you think that this measure would be most appropriate/efficient?	Please give examples	
Are there other restoration-like measures that you think that should be mentioned/evaluated in your country/area/sub-basin?	Please give examples	

Figure 2, from HELCOM (2010), illustrates the richness of habitat types (named ecosystem components) in different parts of the Baltic Sea. The categorization of the ecosystem components in this figure closely resembles the habitat and biotope concept used in this review, apart from a few classes based on species data and deeper aphotic bottoms away from the coast. Still, it can, in our opinion, be used as a proxy for potential restoration targets in the Baltic Sea.

In the context of Figure 2, an ecosystem component refers to biological parts of the ecosystem such as species, biotopes formed by habitat-forming species or abiotic biotopes with a clear linkage to certain species (Korpinen et al. 2012). The 14 named ecosystem components in Korpinen et al. (2012) are divided into benthic biotopes (two), benthic biotope complexes (six), water column (two) and species data (four). In the map, the habitats specifically constitute: 1) mussel beds and 2) eelgrass meadows (benthic biotopes); 3) photic sand, 4) non-photic sand, 5) photic mud and clay, 6) non-photic mud and clay, 7) photic hard bottom and 8) non-photic hard bottom (benthic biotope complexes); 9) photic water and 10) non-photic water (water column); as well as 11) harbour porpoise, 12) seals, 13) seabird wintering grounds and 14) spawning and nursery areas of cod (species data). Note, that for the purposes of this report, a number of ecosystem components from the list above are not fully synonymous to restoration targets, as the term is interpreted and used here. This clearly applies to the species data points 11–13 above, but also partly to non-photic bottoms (points 4, 6 and 8 above) and non-photic water column (point 10), i.e. for those parts that are occurring deeper down and farther away from the coast.

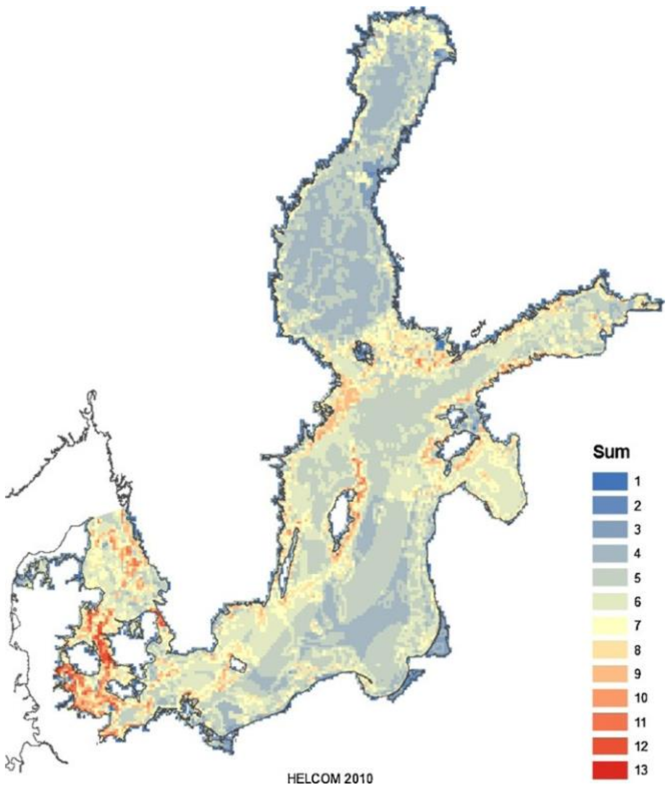

Figure 2. Map showing the number of ecosystem components present (benthic and water column biotope complexes, benthic biotopes and species-related data layers) as a proxy for restoration targets in 5 km × 5 km squares in the Baltic Sea. Altogether 14 data layers were used when constructing the map, but no single square contained all ecosystem components. The map is taken from HELCOM (2010), with permission.

If the ecosystem components from HELCOM (2010) and Korpinen et al. (2012) and presumed restoration targets in the Baltic Sea are considered to be of the same kind, the richest diversity of components/targets will then be found in squares in the south-western Baltic Sea, for example in the Sound, in the Belts and in Kattegat. A reasonably high diversity of components/targets are also found around the large islands and in the archipelagos of the central Baltic Proper. Lower diversities (fewer components/targets) are found in the Bothnian Bay and in the eastern parts of the Baltic Sea (Figure 2).

As a spatial representation for weighing large numbers of cumulative human impacts against ecosystem components and describing the current condition of various part of the sea area, the Baltic Sea Impact Index has been developed (see Halpern et al. 2008, HELCOM 2010, 2018 and Table 2 in Korpinen et al. 2012 for details). This index shows that the lowest cumulative impact is generally found in the Gulf of Bothnia in the sparsely populated northernmost part of the Baltic Sea, and the highest impacts mainly occur in the coastal areas of southern and south-western Finland, along the northern and western coast of Estonia, along the eastern and western coast of south Sweden, in the Polish Bay of Gdansk and in the Danish and German parts of the Baltic Sea (Figure 3). This impact map may be regarded as closely reflecting the general pressures on potential restoration targets, as well.

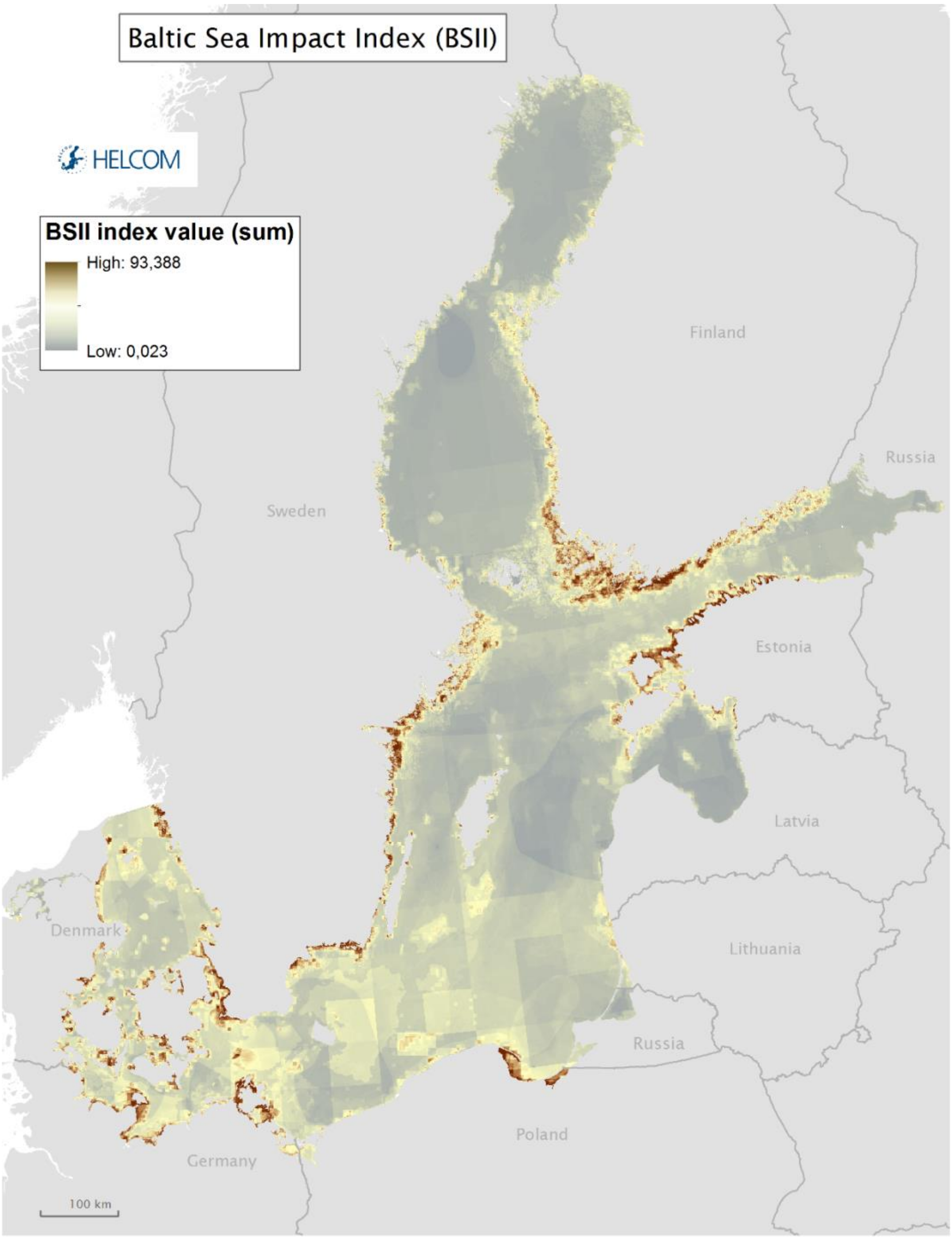

Figure 3. Presentation of cumulative potential anthropogenic impacts by the Baltic Sea Impact Index in 5 km × 5 km assessment units. The index in each assessment unit consists of the sum of anthropogenic impacts on selected ecosystem components present in the unit. The original index formula is from Halpern et al. (2008) and Korpinen et al. (2012). The map is taken from HELCOM (2018), with permission.

In addition to mentioning the geographical areas in the Baltic Sea where the various restoration has been tested/attempted (see details in chapters 2.1–2.15

Geographical areas in the Baltic Sea where the restoration has been tested/attempted), we also provide the following general estimates about in which areas the various restoration measures may be of greatest need:

1. **Restoration of eelgrass, *Zostera marina*:** This may be a relevant measure in more or less all areas with eelgrass, but especially in Danish waters; in Kattegat, western Sweden; along all coasts of the Baltic Proper; in the Åland Sea and in the Finnish and Estonian parts of the Gulf of Finland.
2. **Restoration of soft bottom macrophytes (other than eelgrass):** This may be a relevant measure where this habitat type is being damaged or lost, but especially along the coasts of the Baltic Proper; in the Åland Sea; in the Finnish and Estonian parts of the Gulf of Finland; in the Gulf of Riga; in the Gulf of Bothnia.
3. **Restoration of brown macroalgae, mainly *Fucus vesiculosus*:** This may be a relevant measure along the coasts of the Baltic Proper; in the Åland Sea and in the Finnish and Estonian parts of the Gulf of Finland.
4. **Restoration of blue mussel reefs:** This may be a relevant measure especially in Danish waters and in Kattegat/Skagerrak in western Sweden, but potentially also along coasts of the Baltic Proper.
5. **Restoration of stony reefs in areas where these have previously been lost:** This may be a relevant measure in Danish waters and in southern Sweden, i.e. in areas where stony reefs once were present, but now are lost.
6. **Restoration of soft bottoms naturally free of vegetation:** This may be a relevant measure wherever this habitat type has been lost due to construction work or eutrophication causing e.g. drifting algal mats.
7. **Restoration of coastal wetlands and fladas/lagoons:** This may be a relevant measure along the Polish and German north coasts, in many parts of the Baltic Proper, in the Åland Sea; in the Gulf of Finland and in the Gulf of Bothnia.
8. **Invigorating piscivorous fish populations to rehabilitate coastal ecosystem function:** This may be a relevant measure more or less everywhere in the Baltic Sea concerning different species though with cod in more saline and offshore areas and pike and perch in less saline and coastal areas.
9. **Reducing nutrient loading by farming and harvesting blue mussels:** This may be a relevant measure in Kattegat; in the southern Baltic Sea as well as along the coasts of the Baltic Proper.
10. **Rehabilitation of hypoxic areas by oxygen pumping:** This may be a relevant measure in inner bays of the Baltic Proper, in the Åland Sea, in the Gulf of Finland and in the Gulf of Bothnia.
11. **Reducing internal phosphorus loads by metal binding:** This may be a relevant measure in inner bays of the Baltic Proper, in the Åland Sea, in the Gulf of Finland and in the Gulf of Bothnia.
12. **Investigative and trial biomanipulation by removing cyprinids and sticklebacks as a method for rehabilitating coastal ecosystems:** This may

be a relevant measure in the Baltic Proper, in the Åland Sea, in the Gulf of Finland and in the Gulf of Bothnia.

13. **Rehabilitation of anoxic, nutrient rich or polluted sediments by removal or coverage:** This may be a relevant measure in polluted harbour areas and in industrial recipients all through the Baltic Sea.
14. **Establishment of artificial reefs:** This may be a relevant measure in parts of Danish waters and the Southern Sweden in areas with historical loss of stony reefs due to human impact. The measure is only to be considered for areas with historical loss of the substrate that the reef mimics.
15. **Protection of habitats:** This may be a relevant measure everywhere in the Baltic Sea.
16. **Follow-up and knowledge sharing:** This may be a relevant measure everywhere in the Baltic Sea.

5. General Conclusions

- In order for restoration measures to be effective, the activities and pressures originally causing the disturbance/loss should first be removed.
- Most coastal restoration measures, if successful, show an effect at the scale of small/closed coastal systems rather than at larger (basin-wide) scales. A possible exception may be measures to enhance the production of predatory fish.
- In general, active restoration may work better in closed and sheltered areas than in open and exposed areas. For open areas, facilitating natural passive recovery may be a more effective approach.
- Protection allowing for passive recovery may in many cases be more efficient and less costly than active restoration measures.
- An apt rule of thumb is that it is much less costly to initially prevent environmental damage in the coastal zone than to later have to rely on restoring damaged habitats or areas.
- A combination of several restoration measures in the same area is often preferable and may boost the success rates. This is partly because many pressures are acting simultaneously and many activities are impacting areas cumulatively.
- The spatial allocation of restoration efforts should be planned with a focus on green infrastructure, prioritizing restoration measures that improve the ecological connectivity of marine and coastal landscapes. This may especially concern protected areas, restored areas, migration barriers, rivers, fladas, wetlands and water ways.
- The efficiency of different restoration measures should be quantitatively evaluated to ensure adaptive learning and knowledge sharing.
- On the basis of expert evaluations in connection with this project, restoration measures such as restoration of coastal wetlands and protection of habitats rank at the highest end (most feasible/effective), whereas many traditional habitat restoration measures are considered less feasible/effective (found in the middle of the table). Some rehabilitating and physico-chemical measures are ranked the lowest.
- Different restoration measures may be advisable in different geographic areas based on e.g. local community composition and key species, local physical habitat characteristics as well as identified key environmental pressures.
- The most impacted coastal areas in the Baltic Sea occur in southern and south-western Finland, along the northern and western coast of Estonia, along the eastern and western coast of south Sweden, in the Polish Bay of Gdansk and in the Danish and German parts of the Baltic Sea. These areas may also be the ones with the greatest need for restoration measures, as well.

6. References

Abelson, A., Nelson, P.A., Edgar, G.J., Shasar, N., Reed, D.C., Belmaker, J., Krause, G., Beck, M.W., Brokovich E., France, R., Gaines, S.D., 2016. Expanding marine protected areas to include degraded coral reefs. Conserv Biol 30:1182-1191.

Adams, S.M., 2005. Assessing cause and effect of multiple stressors on marine systems. Mar Pollut Bull 51:649-657.

Ailstock, M.S., Shafer, D.J., Magoun, A.D., 2010a. Protocols for use of *Potamogeton perfoliatus* and *Ruppia maritima* seeds in large-scale restoration. Restor Ecol 18:560-573.

Ailstock, M.S., Shafer, D.J., Magoun, A.D., 2010b. Effects of planting depth, sediment grain size, and nutrients on *Ruppia maritima* and *Potamogeton perfoliatus* seedling emergence and growth. Restor Ecol 18:574-583.

Akcil, A., Erust, C., Ozdemiroglu, S., Fonti, V., Beolchini, F., 2015. A review of approaches and techniques used in aquatic contaminated sediments: metal removal and stabilization by chemical and biotechnological processes. J Clean Prod 86:24-36.

Andersen, J.H., Halpern, B.S., Korpinen, S., Murray, C., Reker, J., 2015. Baltic Sea biodiversity status vs. cumulative human pressures. Estuar Coast Shelf Sci 161:88-92.

Andersen, S., Grefsrud, E.S., Mortensen, S., Naustvoll, L.J., Strand, Ø., Strohmeier, T., Sælemyr, L., 2016. Reports on disappearing blue mussels – summing up for 2016. Institute of Marine Research Report 4-2017 (in Norwegian)

Apler, A., Nyberg, J., 2011. Metoder för att kartlägga fiberhaltiga sediment. SGU-rapport 2011:1. (In Swedish)

Apler, A., Nyberg, J., Jönsson, K., Hedlund, I., Heinemo, S.-Å., Kjellin, B., 2014. Kartläggning av fiberhaltiga sediment längs Västernorrlands kust. Sveriges Geologiska Undersökning, SGU-rapport 2014:16, 178 s. (In Swedish)

Arheimer, B., Pers, B.C., 2017. Lessons learned? Effects of nutrient reductions from constructing wetlands in 1996–2006 across Sweden. Ecol Engineer 103 (Part B):404-414.

Aronson, J., 2010. What can and should be legalized in ecological restoration? Revista Arvore 34:451-454.

Bachmann, R.W., Hoyer, M.V., Canfield D.E., 1999. The restoration of Lake Apopka in relation to alternative stable states. Hydrobiologia 394:219-232.

Baggett, L.P., Powers, S.P., Brumbaugh, R.D., Coen, L.D., DeAngelis, B.M., Greene, J.K., Hancock, B.T., Morlock, S.M., Allen, B.L., Breitburg, D.L., Bushek, D., Grabowski, J.H., Grizzle, R.E., Grosholz, E.D., La Peyre, M.K., Luckenbach, M.W., McGraw K.A., Piehler, M.F., Westby, S.R., zu Ermgassen, P.S.E., 2015. Guidelines for evaluating performance of oyster habitat restoration. Restor Ecol 23:737-745.

Baine, M., 2001. Artificial reefs: a review of their design, application, management and performance. Ocean Coast Manage 44:241-259.

Balazy, P., Copeland, U., Sokołowski, A., 2019. Shipwrecks and underwater objects of the southern Baltic–Hard substrata islands in the brackish, soft bottom marine environment. Estuar Coast Shelf Sci 225:106240.

Bakker, E.S., Sarneel, J.M., Gulati, R.D., Liu, Z., van Donk, E., 2013. Restoring macrophyte diversity in shallow temperate lakes: biotic versus abiotic constraints. Hydrobiologia 710:23-37.

Bas, A., Jacob, C., Hay, J., Pioch, S., Thorin, S., 2016. Improving marine biodiversity offsetting: a proposed methodology for better assessing loses and gains. J Mar Manage 175:46-59.

Bayraktarov, E., Saunders, M.I., Abdullah, S., Mills, M., Beher, J., Possingham, H.P., Mumby, P.J., Lovelock, C.E., 2016. The cost and feasibility of marine coastal restoration. Ecol Appl 26:1055-1074.

Beaumont, N.J., Austen, M.C., Atkins, J.P., Burdon, D., Degraer, S., Dentinho, T.P., Derous, S., Holm, P., Horton, T., van Ierland, E., Marboe, A.H., Starkey, D.J., Townsend, M., Zarzycki, T., 2007. Identification, definition and quantification of goods and services provided by marine biodiversity: Implications for the ecosystem approach. Mar Pollut Bull 54:253-265.

Beck, M.W., Brumbaugh, R.D., Airoldi, L., Carranza, A., Coen, L.D., Crawford, C., Defeo, O., Edgar, G.J., Hancock, B., Kay, M.C., Lenihan, H.S., Luckenbach, M.W., Toropova, C.L., Zhang, G., Guo, X., 2011. Oyster reefs at risk and recommendations for conservation, restoration, and management. Bioscience 61:107-116.

Bekkby, T., Moy, F.E., 2011. Developing spatial models of sugar kelp (*Saccharina latissima*) potential distribution under natural conditions and areas of its disappearance in Skagerrak. Estuar Coast Shelf Sci 95:477-483.

Bellew, S., Drabble, R.C., 2004. Marine aggregate site restoration & enhancement: a strategic feasibility and policy review. A report prepared by Emu Ltd., commissioned by BMAPA and The Crown Estate.

Bendtsen, J., Gustafsson, K.E., Lehtoranta, J., Saarijärvi, E., Rasmus, K., Pitkänen, H., 2013: Modeling and tracer release experiment on forced buoyant plume convection from coastal oxygenation. Bor Environ Res 18: 37-52.

Berger, R., Malm, T., Kautsky, L., 2001. Two reproductive strategies in Baltic *Fucus vesiculosus* L. Eur J Phycol 36:265-273.

Bergström, L., Sundqvist, F., Bergström, U., 2013. Effects of an offshore wind farm on the local demersal fish community. Mar Ecol Prog Ser 485:199-210.

Bergström, L., Karlsson, M., Bergström, U., Pihl, L., Kraufvelin, P., 2019. Relative impacts of fishing and eutrophication on coastal fish assessed by comparing a no-take area with an environmental gradient. Ambio 48:565-579.

Bergström, P., Carlsson, M.S., Lindegarth, M., Petersen, J.K., Lindegarth, S., Holmer, M., 2017. Testing the potential for improving quality of sediments impacted by mussel farms using bioturbating polychaete worms. Aquacult Res 48:161-176.

Bergström, U., Olsson, J., Casini, M., Eriksson, B. K., Fredriksson, R., Wennhage, H., Appelberg, M., 2015. Stickleback increase in the Baltic Sea – A thorny issue for coastal predatory fish. Estuar Coast Shelf Sci 163:134-142.

Bergström, U., Sköld, M., Wennhage, H., Wikström, A., 2016. Ekologiska effekter av fiskefria områden i Sveriges kust- och havsområden. Aqua reports 2016:20. Institutionen för akvatiska resurser, Sveriges lantbruksuniversitet, Öregrund. 207 pp. (In Swedish).

Berkström, C., Wennerström, L., Bergström, U., 2019. Ekologisk konnektivitet i svenska kust- och havsområden. Öregrund, Drottningholm, Lysekil: Sveriges lantbruksuniversitet. Aqua reports 2019:15

Bohnsack, J.A., Sutherland, D.L., 1985. Artificial reef research: a review with recommendations for future priorities. Bull Mar Sci 37:11-39.

Bolam, S.G., Schratzberger, M., Whomersley, P., 2006. Macro- and meiofaunal recolonisation of dredged material used for habitat enhancement: Temporal patterns in community development. Mar Pollut Bull 52:1746-1755.

Borja, A., 2014. Grand challenges in marine ecosystems ecology. Front Mar Sci 1:1.

Borja, A., Dauer, D.M., 2008. Assessing the environmental quality status in estuarine and coastal systems: Comparing methodologies and indices. Ecol Indic 8:331-337.

Borja, A., Dauer, D.M., Elliott, M., Simenstad, C.A., 2010. Medium-and long-term recovery of estuarine and coastal ecosystems: patterns, rates and restoration effectiveness. Estuar Coast 33:1249-1260.

Bostedt, G., Berkström, C., Brännlund, R., Carlén, O., Florin, A.B., Persson, L., Bergström, U., 2020. Benefits and costs of two temporary no-take zones. Mar Pol 103883.

Boyd, S.E., Limpenny, D.S., Rees, H.L., Cooper, K.M., Campbell, S., 2003. Preliminary observations of the effects of dredging intensity on the re-colonisation of dredged sediments off the southeast coast of England (Area 222). Estuar Coast Shelf Sci 57:209-223.

Bradshaw, A.D., 1996. Underlying principles of restoration. Can J Fish Aquat Sci 53:3-9.

Brumbaugh, R.D., Sorabella, L.A., García, C.O., Goldsborough, W.J., Wesson, J.A., 2000. Making a case for community-based oyster restoration: An example from Chesapeake Bay. J Shellfish Res 19:467-472.

Bryhn A, Kraufvelin P, Bergström U, Vretborn M, Bergström L (2020) A model for disentangling dependencies and impacts among human activities and marine ecosystem services. Environ Manage (in press).

Buckley, R.M., 1982. Marine habitat enhancement and urban recreational fishing in Washington. Mar Fish Rev 44:28-37.

Buer, A.-L., Maar, M., Nepf, M., Ritzenhofen, L., Dahlke, S., Friedland, R., Krost, P., Peine, F., Schernewski, G., 2020. Potential and feasibility of *Mytilus* spp. farming along a salinity gradient. Front Mar Sci 7:371.

Bulleri, F., Chapman, M.G., 2010. The introduction of coastal infrastructure as a driver of change in marine environments. J Appl Ecol 47:26-35.

Burek, K., O'Brien, J., Scheibling, R., 2018. Wasted effort: recruitment and persistence of kelp on algal turf. Mar Ecol Prog Ser 600:3-19.

Byström, P., Bergström, U., Hjälten, A., Ståhl, S., Jonsson, D., Olsson, J., 2015. Declining coastal piscivore populations in the Baltic Sea: Where and when do sticklebacks matter? Ambio 44:462-471.

Calumpong, H.P., Fonseca, M.S., 2001. Seagrass transplantation and other seagrass. Global seagrass research methods 33:425.

Campbell, A.H., Marzinelli, E.M., Vergés, A., Coleman, M.A., Steinberg, P.D., 2014. Towards restoration of missing underwater forests. PLoS One 9:e84106.

Carlsson M.S., Holmer M., Petersen J.K., 2009. Seasonal and spatial variation of benthic impacts of mussel long-line farming in a eutrophicated Danish fjord, Limfjorden. J Shellfish Res 28:791-801.

Carney, L.T., Waaland, J.R., Klinger, T., Ewing, K., 2005. Restoration of the bull kelp *Nereocystis luetkeana* in nearshore rocky habitats. Mar Ecol Prog Ser 302:49-61.

Carter, R.W.G., 1989. Coastal Environments – An Introduction to the Physical, Ecological and Cultural Systems of Coastlines. Academic Press, London, 617 pp.

Chapman, M.G., 2012. Restoring intertidal boulder-fields as habitat for "specialist" and "generalist" animals. Restor Ecol 20:277-285.

Christie, H., 2005a. Kunstige rev på norskekysten. S. 83-85 i Kyst og havbruk 2005, Boxaspen, K., Agnalt, A.L., Gjøsæter, J., Jørgensen, L.L., Skiftesvik A.B. (Red.), Fisken og havet, særnummer 2 – 2005, Havforskningsinstituttet. (In Norwegian).

Christie, H., 2005b. Hummer, rev og skjell. S. 171-172 i Kyst og havbruk 2005, Boxaspen, K., Agnalt, A.L., Gjøsæter, J., Jørgensen, L.L., Skiftesvik A.B. (Red.), Fisken og havet, særnummer 2 – 2005, Havforskningsinstituttet. (In Norwegian).

Christie, H., 2007. Artificial reefs (Runde Reef) in South Norway - Test report for two Runde reefs, 2002-2006. Norwegian Institute for Water Research (NIVA), Oslo, 10 pp.

Christie, H., Fredriksen, S., 2011. Restituering av plante- og dyreliv i Bjørvika. Utsettning av stein med tang og utsettning av kunstige rev utenfor operaen i Bjørvika. Rapport Til Oslo Havn, Universitetet i Oslo. 9 pp.

Christie, H., Kraufvelin, P., Kraufvelin, L., Niemi, N., Rinde, E., 2020. Disappearing blue mussels – can mesopredators be blamed? Front Mar Sci 7:550

Claisse, J.T., Pondella, D.J., Love, M., Zahn, L.A., Williams, C.M., Williams, J.P., Bull, A.S., 2014. Oil platforms off California are among the most productive marine fish habitats globally. P Natl Acad Sci 111:15462-15467.

Clewell, A.F., Rieger, J., Munro, J., 2000. Guidelines for developing and managing ecological restoration projects. Publications Working Group. Society for Ecological Restoration: 11 pp.

Coen, L.D, Luckenbach, M.W., 2000. Developing success criteria and goals for evaluating oyster reef restoration: Ecological function or resource exploitation? Ecol Eng 15:323-343.

Coen, L.D., Brumbaugh, R.D., Bushek, D., Grizzle, R., Luckenbach, M.W., Posey, M.H., Powers, S.P., Tolley, S.G., 2007. Ecosystem services related to oyster restoration. Mar Ecol Prog Ser 341:303-307.

Connell, J.H., Slatyer, R.O., 1977. Mechanisms of succession in natural communities and their role in community stability and organization. Am Nat 111:1119-1144.

Crain, C.M., Kroeker, K., Halpern, B.S., 2008. Interactive and cumulative effects of multiple human stressors in marine systems. Ecol Lett 11:1304-1315.

Cole, G.S., Moksnes, P.-O., 2016. Valuing multiple eelgrass ecosystem services in Sweden: fish production and uptake of carbon and nitrogen. Front Mar Sci 2:121.

Conley, D.J., Bonsdorff, E., Carstensen, J., Destouni, G., Gustafsson, B.G., Hansson, L.A, Rabalais, N, Voss, M., Zillén, L., 2009. Tackling hypoxia in the Baltic Sea: is engineering a solution? Environ Sci Technol 43:3407-3411.

Cooke, G.D., Welch, E.B., Peterson, S., Nichols, S.A., 2016. Restoration and management of lakes and reservoirs. CRC press.

Cooper, K., Burdon, D., Atkins, J.P., Weiss, L., Somerfield, P., Elliott, M., Turner, K., Ware, S., Vivian, C., 2013. Can the benefits of physical seabed restoration justify the costs? An assessment of a disused aggregate extraction site off the Thames Estuary, UK. Mar Pollut Bull 75:33-45.

Crisp, D.J., 1967. Chemical factors inducing settlement in *Crassostrea virginica* (Gmelin). J Anim Ecol 36:329-335.

Cronk, J.K., Fennessy, M.S., 2016. Wetland plants: biology and ecology. CRC press.

Dafforn, K.A., Glasby, T.M., Airoldi, L., Rivero, N.K., Mayer-Pinto, M., Johnston, E.L., 2015. Marine urbanization: an ecological framework for designing multifunctional artificial structures. Front Ecol Environ 13:82-90.

Davis, R.C., Short, F.T., 1997. Restoring eelgrass, *Zostera marina* L., habitat using a new transplanting technique: the horizontal rhizome method. Aquat Bot 59:1-15.

De'ath, G., Fabricius, K.E., Sweatman, J., Puotinen, M., 2012. The 27-year decline of coral cover on the Great Barrier Reef and its causes. P Nat Acad Sci 109:17995-17999.

Degerman, E., 2008. Ekologisk restaurering av vattendrag. Fiskeriverket 6, 300 s. (In Swedish).

Degerman, E., Tamario, C., Sandin, L., Törnblom, J., 2017. Fysisk restaurering av sjöar. Aqua reports 2017:10. Institutionen för akvatiska resurser, Sveriges lantbruksuniversitet, Drottningholm Lysekil Öregrund, 105 s. (In Swedish).

Degraer, S., Brabant, R., Rumes, B. (eds.), 2011. Offshore wind farms in Belgian part of the North Sea: Selected findings from the baseline and target monitoring. Royal Belgian

Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models. Marine ecosystem management unit. 157 pp. + annex.

de Groot, R.S., Brander, L., van der Ploeg, S., Costanza, R., Bernard, F., Braat, L., Christie, M., Crossman, N., Ghermandi, A., Hein, L., Hussain, S., Kumar, P., McVittie, A., Portela, R., Rodriguez, L.C., ten Brink, P., van Beukering, P., 2012. Global estimates of the value of ecosystems and their services in monetary units. Ecosyst Serv 1:50-61.

De Jonge, V.N., 2000. Policy plans and management measures to restore eelgrass (*Zostera marina* L.) in the Dutch Wadden Sea. Helgol Mar Res, 54:151-158.

Deysher, L.E., Dean, T.A., Grove, R.S., Jahn, A., 2002. Design considerations for an artificial reef to grow giant kelp (*Macrocystis pyrifera*) in Southern California. ICES J Mar Sci 59 (Supplement 1):S201-S207.

Dolmer, P., Kristensen, P.S., Hoffman, E., Geitner, K., Borgström, R., Espersen, A., Petersen, J.K., Clausen, P., Bassompierre, M., Josefson, A., Laursen, K., Petersen, I.K., Tørring, D., Gramkow, M., 2009. Udvikling af kulturbanker til produktion af blåmuslinger i Limfjorden. DTU Aqua-rapport nr. 212-2009. Charlottenlund. Institut for Akvatiske Ressourcer, Danmarks Tekniske Universitet, 127 p. (In Danish).

Donadi, S., Austin, Å.N., Bergström, U., Eriksson, B.K., Hansen, J.P., Jacobson, P., Sundblad, G., van Regteren, M., Eklöf, J.S., 2017. A cross-scale trophic cascade from large predatory fish to algae in coastal ecosystems. Proc R Soc B 284:20170045.

Duarte, C., Conley, D., Carstensen, J., Sánchez-Camacho., M., 2009. Return to Neverland: Shifting baselines affect eutrophication restoration targets. Estuar Coast 32:29-36.

Duarte, C.M., Borja, A., Carstensen, J., Elliott, M., Krause-Jensen, D., Marbá, N., 2015. Paradigms in the recovery of estuarine and coastal ecosystems. Estuar Coast 38:1202-1212.

Duarte, C.M., Agusti, S., Barbier, E., Britten, G.L., Castilla, J.C., Gattuso, J.-P., Fulweiler, R.W., Hughes, T.P., Knowlton, N., Lovelock, C.E., Lotze, H.K., Predragovic, M., Poloczanska, E., Roberts, C., Worm, B., 2020. Rebuilding marine life. Nature 580:39-51.

Egriell, N., Ulmestrand, M., Andersson, J., Gustavsson, B., Lundälv, T., Erlandsson, C., Jonsson, L., Åhsberg, T., 2007. Hummerrevsprojektet, slutrapport 2007. Konstgjorda rev i Göteborgs skärgård (år 2002–2007). Länsstyrelsen i Västra Götalands län. Rapport 2007:40, 128. (In Swedish).

Elliott, M., 2004. Marine habitats: loss and gain, mitigation and compensation. Mar Pollut Bull 49:671-674.

Elliott, M., Burdon, D., Hemingway, K.L., Apitz, S.E., 2007. Estuarine, coastal and marine ecosystem restoration: Confusing management and science – A revision of concepts. Estuar Coast Shelf Sci 74:349-366.

Elliott, M., Mander, L., Mazik, K., Simenstad, C., Valesini, F., Whitfield, A., Wolanski, E., 2016. Ecoengineering with Ecohydrology: Successes and failures in estuarine restoration. Estuar Coast Shelf Sci 176:12-35.

Ellison, A.M., 2000. Mangrove restoration: do we know enough? Restor Ecol 8:219-229.

Elsäßer, B., Fariñas-Franco, J.M., Wilson, C.D., Kregting, L., Roberts, D., 2013. Identifying optimal sites for natural recovery and restoration of impacted biogenic habitats in a special area of conservation using hydrodynamic and habitat suitability modelling. J Sea Res 77:11-21.

Engkvist, R., Malm, T., Tobiasson, S., 2000. Density dependent grazing effects of the isopod *Idotea baltica* Pallas on *Fucus vesiculosus* L in the Baltic Sea. Aquat Ecol 34:253-260.

Engstedt, O., Stenroth, P., Larsson, P., Ljunggren, L., Elfman, M., 2010. Assessment of natal origin of pike (*Esox lucius*) in the Baltic Sea using Sr:Ca in otoliths. Environ Biol Fish 89: 547-555.

Epstein, N., Bak, R.P.M., Rinkevich, B., 2001. Strategies for gardening denuded coral reef areas: the applicability of using different types of coral material for reef restoration. Restor Ecol 9:432-442.

Eriander, L., Infantes, E., Olofsson, M., Olsen, J.L., Moksnes, P.O., 2016. Assessing methods for restoration of eelgrass (*Zostera marina* L.) in a cold temperate region. J Exp Mar Biol Ecol 479:76-88.

Eriksson, B.K., Ljunggren, L., Sandström, A., Johansson, G., Mattila, J., Rubach, A., Råberg, S., Snickars, M., 2009. Declines in predatory fish promote bloom-forming macroalgae. Ecol Appl 19:1975-1988.

Eriksson, J., Foster, A., Lindberg, M., 2016. Applying Freeze Technology for Characterisation of Liquids, Sludge and Sediment (No. NEA-PREDEC--2016).

Fabi, G., Spagnolo, A., Bellan-Santini, D., Charbonnel, E., Cicek, B.A., Goutayer Garcia, J.J., Jensen, A.C., Kallianiotis, A., dos Santos, M.N., 2011. Overview on artificial reefs in Europe. Brazil J Oceanogr 59:155-166.

Ferrario, F., Iveša, L., Jaklin, A., Perkol-Finkel, S, Airoldi, L., 2016. The overlooked role of biotic factors in controlling the ecological performance of artificial marine habitats. J Appl Ecol 53:16-24.

Firth, L.B., Thompson, R.C., Bohn, K., Abbiati, M., Airoldi, L., Bouma, T.J., Bozzeda, F., Ceccherelli, V.U., Colangelo, M.A., Evans, A., Ferrario, F., Hanley, M.E., Hinz, H., Hoggart, S.P.G., Jackson, J.E., Moore, P., Morgan, E.H., Perkol-Finkel, S., Skov, M.W., Strain, E.M., van Belzen, J., Hawkins, S.J., 2014. Between a rock and a hard place: Environmental and engineering considerations when designing coastal defence structures. Coastal Eng 87:122-135.

Fonseca, M.S., 2011. Addy revisited: what has changed with seagrass restoration in 64 years? Ecol Rest 29:73-81.

France, R.L., 2016. From land to sea: governance-management lessons from terrestrial restoration research useful for developing and expanding social-ecological marine restoration. Ocean Coast Manage 133:64-71.

Fredriksen, S., Filbee-Dexter, K., Norderhaug, K.M., Steen, H., Bodvin, T., Coleman, M.A., Moy, F., Wernberg, T., 2020. Green gravel: a novel restoration tool to combat kelp forest decline. Sci Rep UK 10:1-7.

Fredriksson, R., Bergström, U., Olsson, J., 2013 Riktlinjer för uppföljning av fiskevårdsåtgärder i kustmynnande våtmarker med fokus på gädda. (Guidance for the follow-up of measures to restore freshwater tributaries with a focus on pike). Aqua Reports 2013:7. Department of Aquatic Resources, Swedish University of Agricultural Sciences, Öregrund, Sweden. 52 pp. (in Swedish with English summary).

Frigstad, H., Andersen, G.S., Trannum, H.C., Naustvoll, L.-J., Kaste, Ø., Hjermann, D.Ø., 2018. Synthesis of climate relevant results from selected monitoring programs in the coastal zone. Part 2: Quantitative analyses. Miljødirektoratet rapport M-1220|2018.

Gagnon, K., Alan V., Bakran-Petricioli, T., Bengil, E.G.T., Carugati, L., Christianen, M.J.A., Christie, H., Danovaro, R., Da Ros, Z., Gambi, C., Lo Martire, M. Govers, L.L., Gräfnings, M., Kipson, S., Martin, G., Meysick, L., Pajusalu, L., Rinde, E., Tüney Kızılkaya, İ., van der Heide, T., 2019. Manual of restoration measures in soft bottoms based on surveys and experiments. MERCES Project Work Package 2 Deliverable 2.1 November 2019.

Geist, J., Hawkins, S.J., 2016. Habitat recovery and restoration in aquatic ecosystems: current progress and future challenges. Aquat Conserv 26:942-962.

George, L.M., De Santiago, K., Palmer, T.A., Pollack, J.B., 2015. Oyster reef restoration: effect of alternative substrates on oyster recruitment and nekton habitat use. J Coast Conserv 19:13-22.

Gorgula, S., Connell, S., 2004. Expansive covers of turf-forming algae on human-dominated coast: the relative effects of increasing nutrient and sediment loads. Mar Biol 145:613-619.

Grabowski, J.H., Brumbaugh, R.D., Conrad, R.F., Keeler, A.G., Opaluch, J.J., Peterson, C.H., Piehler, M.F., Powers, S.P., Smyth, A. R. (2012). Economic valuation of ecosystem services provided by oyster reefs. Bioscience 62:900-909.

Grove, R.S., Sonu, C.J., Nakamura, M., 1989. Recent Japanese trends in fishing reef design and planning. Bull Mar Sci 44:984-996.

Gulati, R.D., Pires, L.M.D., van Donk, E., 2008. Lake restoration studies: failures, bottlenecks and prospects of new ecotechnological measures. Limnologica, 38:233-247.

Håkanson, L., Bryhn, A.C., 2010. Controlling eutrophication in the Baltic Sea and the Kattegat. I: Ansari, A.A. (red.) Eutrophication: Causes, Consequences and Control. Springer, Berlin, s. 17-67.

Halpern, B.S., Walbridge, S., Selkoe, K.A., Kappel, C.V., Micheli, F., D'Agrosa, C., Bruno, J.F., Casey, K.S., Ebert, C., Fox, H.E., Fujita, R., Heinemann, D., Lenihan, H.S., Madin, E.M.P., Perry, M.T., Selig, E.R., Spalding, M., Steneck, R., Watson, R., 2008. A global map of human impact on marine ecosystems. Science 319:948-952.

Hansen J.P., Sundblad, G., Bergström, U., Austin, Å.N., Donadi, S., Eriksson, B.K., Eklöf, J.S., 2018. Recreational boating degrades vegetation important for fish recruitment. Ambio 48:539-551.

Hansen, J., Anderson, H.C., Bergström, U., Borger, T., Brelin, D., Byström, P., Eklöf, J., Kraufvelin, P., Kumblad, L., Ljunggren, L., Nordahl, O., Tibblin, P., 2020. Våtmarker som fiskevårdsåtgärd vid kusten. Utvärdering av restaurerade våtmarkers effekt på fiskreproduktion och ekosystemet längs Östersjökusten. (Wetlands as a management tool for coastal fish in the Baltic Sea. An evaluation of the effects of restored wetlands on fish recruitment and the ecosystem along the Swedish coast). Stockholms universitets Östersjöcentrum, rapport 1/2020. (In Swedish, English abstract).

Hansson, L.A., Annadotter, H., Bergman, E., Hamrin, S.F., Jeppesen, E., Kairesalo, T., Luokkanen, E., Nilsson, P.Å., Søndergaard, M., Strand, J., 1998. Biomanipulation as an application of food-chain theory: constraints, synthesis, and recommendations for temperate lakes. Ecosystems 1:558-574.

Harlén, A., Zackrisson, A.-C., 2001. Ekonomisk analys av algskörd och användning av fintrådiga alger. EU Life Algae, Rapportnummer 2001:42. (In Swedish).

Harper, D.J., Quigley, J.T., 2005. No net loss of fish habitat: a review and analysis of habitat compensation in Canada. Environ Manage 36:343-355.

Hasselström, L., 2007. Fördjupade ekonomiska kalkyler kring vattenskyddsåtgärder i skärgårdsområden: Slutrapport. BEVIS (Ett gemensamt beslutstödssystem för effektiva vattenskyddsåtgärder i skärgårdarna Åboland-Åland-Stockholm), fas II. (In Swedish).

Havs- och vattenmyndigheten, 2020. Fisk- och skaldjursbestånd i hav och sötvatten 2019. Resursöversikt. Havs- och vattenmyndighetens rapport 2020:3. Göteborg, 322 pp. (In Swedish).

Heath, W., Chambers, K., 2014. Bull Kelp Restoration Project at Hornby Island, BC, Canada.

Hedberg, N., Kautsky, N., Kumblad, L., Wikström, S.A., 2018. Nutrient removal capacity and potential ecological consequences of blue mussel farms for nutrient abatement in the Baltic Sea. Stockholms universitet, 28 s. https://balticeye.org/globalassets/fokusomraden/overgodning/musselfarming/nutrient-removal-capacity-and-potential-ecological-consequences-of-blue-mussel-farms-for-nutrient-abatement-in-the-baltic-sea.pdf

HELCOM, 2010. Towards a tool for quantifying the anthropogenic pressures and potential impacts in the Baltic Sea marine environment. A background document on the method, data preparation and testing of the Baltic Sea Pressure and Impact Indices. Baltic Sea Environment Proceedings 125. Available at: http://www.helcom.fi/helcom-at-work/publications/baltic-sea-environment-proceedings/

HELCOM, 2018. State of the Baltic Sea – Second HELCOM holistic assessment 2011-2016. Baltic Sea Environment. Proceedings 155. Available from: http://stateofthebalticsea.helcom.fi [accessed on: 2020-03-27].

HELCOM, 2021. Methodology, test case and recommendations for assessing the management effectiveness of the Baltic Sea Marine Protected Area (MPA) network. HELCOM ACTION Project.

Hering, D., Borja, A., Carstensen, J. Carvalho, L., Elliott, M., Feld, C.K., Heiskanen, A.S., Johnson, R.K., Moe, J., Pont, D., Solheim, A.L., van de Bund, W., 2010. The European water framework directive at the age of 10: A critical review of the achievements with recommendations for the future. Sci Tot Environ 408:4007-4019.

Hilderbrand, R.H., Watts, A.C., Randle, A.M., 2005. The myths of restoration ecology. Ecol Soc 10:19.

Hilt, S., Gross, E.M., Hupfer, M., Morscheid, H., Mählmann, J., Melzer, A., Poltz, J., Sandrock, S., Scharf, E.M., Schneider, S., Van de Weyer, K., 2006. Restoration of submerged vegetation in shallow eutrophic lakes – a guideline and state of the art in Germany. Limnologica 36:155-171.

Hjerne, O., Hansson, S., 2002. The role of fish and fisheries in Baltic Sea nutrient dynamics. Limnol Oceanogr 47:1023-1032.

Hobbs, R.J., Harris, J.A., 2001. Restoration ecology: repairing the earth's ecosystems in the new millennium. Restor Ecol 9:239-246.

Holbach, A., Maar, M., Timmermann, K., Taylor, D., 2020. A spatial model for nutrient mitigation potential of blue mussel farms in the western Baltic Sea. Sci Total Environ 139624.

Holt, T.J., Rees, E.I., Hawkins, S.J., Seed, R., 1998. Biogenic reefs (Volume IX). An overview of dynamic and sensitivity characteristics for conservation management of marine SACs. Scottish Association for Marine Science (UK Marine SACs Project), 174 pp.

Hulth, S., Sundbäck, K., 2009. Konsekvensanalys av ett borttagande av ytsediment i grunda vikar. Länsstyrelsen i Västra Götalands län. (In Swedish).

Hupfer, M., Lewandowski, J., 2008. Oxygen controls the phosphorus release from lake sediments – a long-lasting paradigm in limnology. Int Rev Hydrobiol 93:415-432.

Huser, B., 2014. Phosphorus binding by aluminium in sediment: a tool for restoring water quality in the Baltic Sea and other brackish surface waters. IVM Report 2014:5. Sveriges lantbruksuniversitet.

Iho, A., Ahtiainen, H., Artell, J., Heikinheimo, O., Kauppila, P., Kosenius, A.-K., Laukkanen, M., LIndroos, M., Oinonen, S., Ollikka, K., Parkkila, K., Pavlova, Y., Peltonen, H., Pouta, E., Uusitalo, L., 2017. The role of fisheries in optimal eutrophication management. Water Econ Pol 3:1650031.

Infantes, E., Eriander, L., Moksnes, P.O., 2016. Eelgrass (*Zostera marina*) restoration on the west coast of Sweden using seeds. Mar Ecol Prog Ser 546:31-45.

Isaksson, I., 2009. Restaurering av övergödda havsvikar i Västerhavets vattendistrikt – redovisning av regeringsuppdrag, Länsstyrelsen i Västra Götalands län Rapport nr 2009:57 (In Swedish).

Jackson, L.L., Lopoukhine, N., Hillyard, D., 1995. Ecological restoration: a definition and comments. Restor Ecol 3:71-75.

Jacob, C., Buffard, A., Pioch, S., Thorin, S., 2018. Marine ecosystem restoration and biodiversity offset. Mar Pol 120:585-594.

Jeppesen, E., Søndergaard, M., Lauridsen, T.L., Davidson, T.A., Liu, Z., Mazzeo, N., Trochine, C., Özkan, K., Jensen, H.S., Trolle, D., Starling, F., Lazzarro, X., Johansson, L.S., Bjerring, R., Liboriussen, L., Larsen, S.E., Landkildehus, F., Egemose, S., Meerhoff, M., 2012. Biomanipulation as a restoration tool to combat eutrophication: recent advances and future challenges. In Advances in ecological research (Vol. 47, pp. 411-488). Academic Press.

Jensen, A., 2002. Artificial reefs in Europe: perspective and future. ICES J Mar Sci 59:S3-S13.

Johnson, G.E., Attrill, M.J., Sheehan, E.V., Somerfield, P.J., 2007. Recovery of meiofauna communities following mudflat disturbance by trampling associated with crab-tiling. Mar Environ Res 64:409-416.

Jokinen, H., Reinikainen, M., 2011. Potential ecological effects of cyprinid reduction fishery in Pikkala Bay. Project Report, Tvärminne Zoological Station, University of Helsinki, Helsinki, Finland. 41 pp.

Jones, H.P., Schmitz, O.J., 2009. Rapid recovery of damaged ecosystems. PLoS ONE 4(5):e5653.

Jones, H.P. Jones, P.C., Barbier, E.B., Blackburn, R.C., Rey Benayas, J.M., Holl K.D., McCrackin, M., Meli, P., Montoya, D., Moreno Mateos, D., 2018. Restoration and repair of Earth's damaged ecosystems. P Roy Soc B 285:20172577.

Karlsson, O.M., Malmaeus, J.M., 2018. Limited capacity to retain phosphorus in the Baltic proper offshore sediments. Ambio 47:379-381.

Kautsky, L., Qvarfordt, S., Schagerström, E., 2019. *Fucus vesiculosus* adapted to a life in the Baltic Sea: impacts on recruitment, growth, re-establishment and restoration. Bot Mar 62:17-30.

Kautsky, L., Qvarfordt, S., Schagerström, E., 2020. Restaurering av blåstångssamhällen i Östersjön. 60 s. ISBN 978-91-982382-3-5. (in Swedish)

Knowlton, N., 2012. Iconic coral reef degraded despite substantial protection. P Natl Acad Sci 109:17734-17735.

Kollmann, J., Meyer, S.T., Bateman, R., Conradi, T., Gossner, M.M., de Souza Mendonça, M., Fernandes, G.W., Hermann, J.-M., Koch, C., Müller, S.C., Oki, Y., Overbeck, G.E., Paterno, G.B., Rosenfield, M.F., Toma, T.S.P., Weisser, W.W., 2016. Integrating ecosystem functions into restoration ecology – recent advances and future directions. Restor Ecol 24:722-730.

Korpinen, S., Meski, L., Andersen, J.H., Laamanen, M., 2012. Human pressures and their potential impact on the Baltic Sea ecosystem. Ecol Indic 15:105-114.

Kotta, J., Futter, M., Kaasik, A., Liversage, K., Rätsep, M., Barboza, F.R., Bergström, L., Bergström, P., Bobsien, I., Díaz, E., Herkül, K., Jonsson, P., Korpinen, S., Kraufvelin, P., Krost, P., Lindahl, O., Lindegarth, M., Moltke Lyngsgaard, M., Mühl, M., Nyström Sandman, A., Orav-Kotta, H., Orlova, M., Skov, H., Rissanen, J., Šiaulys, A., Vidakovic, A., Virtanen, E., 2020a. Cleaning up seas using blue growth initiatives: Mussel farming for eutrophication control in the Baltic Sea. Sci Total Environ 709:136144

Kotta, J., Futter, M., Kaasik, A., Liversage, K., Rätsep, M., Barboza, F.R., Bergström, L., Bergström, P., Bobsien, I., Díaz, E., Herkül, K., Jonsson, P., Korpinen, S., Kraufvelin, P., Krost, P., Lindahl, O., Lindegarth, M., Moltke Lyngsgaard, M., Mühl, M., Nyström Sandman, A., Orav-Kotta, H., Orlova, M., Skov, H., Rissanen, J., Šiaulys, A., Vidakovic, A., Virtanen, E., 2020b. Response to a letter to editor regarding Kotta et al. 2020: Cleaning up seas using blue growth initiatives: Mussel farming for eutrophication control in the Baltic Sea. Sci Total Environ (in press).

Kraufvelin, P., Díaz, E.R., 2015. Sediment macrofauna communities at a small mussel farm in the northern Baltic proper. Bor Environ Res 20:378-390.

Kraufvelin, P., Sinisalo, B., Leppäkoski, E., Mattila, J., Bonsdorff, E., 2001. Changes in zoobenthic community structure after pollution abatement from fish farms in the Archipelago Sea (N Baltic Sea). Mar Environ Res 51:229-245.

Kraufvelin, P., Lindholm, A., Pedersen, M.F., Kirkerud, L.A., Bonsdorff, E., 2010. Biomass, diversity and production of rocky shore macroalgae at two nutrient enrichment and wave action levels. Mar Biol 157:29-47.

Kraufvelin, P., Pekcan-Hekim, Z., Bergström, U., Florin, A.-B., Lehikoinen, A., Mattila, J., Arula, T., Briekmane, L., Brown, E.J., Celmer, Z., Dainys, J., Jokinen, H., Kääriä, P., Kallasvuo, M., Lappalainen, A., Lozys, L., Möller, P., Orio, A., Rohtla, M., Saks, L., Snickars, M., Støttrup, J., Sundblad, G., Taal, I., Ustups, D., Verliin, A., Vetemaa, M., Winkler, H., Wozniczka, A., Olsson, J., 2018. Essential coastal habitats for fish in the Baltic Sea. Estuar Coastal Shelf Sci 204:14-30.

Kraufvelin, P., Christie, H., Gitmark, J.K., 2020a. Top-down release of mesopredatory fish is a weaker structuring driver of temperate rocky shore communities than bottom-up nutrient enrichment. Mar Biol (in press). DOI: 10.1007/s00227-020-3665-3

Kraufvelin, P., Bryhn, A., Olsson, J., 2020b. Erfarenheter av ekologisk restaurering i kust och hav. Havs- och Vattenmyndighetens Rapport (in preparation). (In Swedish).

Kraufvelin, P., Bryhn, A., Olsson, J., 2020c. Fysisk påverkan och biologiska effekter i kustvattenmiljö. Havs- och Vattenmyndighetens Rapport (in preparation). (In Swedish).

Kristensen, L.D., Stenberg, C., Støttrup, J.G., Poulsen, L.K., Christensen, H.T., Dolmer, P., Landes, A., Røjbek, M., Thorsen, S.W., Holmer, M., Deurs, M.V., Grønkjær, P., 2015. Establishment of blue mussel beds to enhance fish habitats. Appl Ecol Environ Res 13:783-798.

Krost, P., Goerres, M., Sandow, V., 2018. Wildlife corridors under water: an approach to preserve marine biodiversity in heavily modified water bodies. J Coastal Conserv 22:87-104.

Kumblad, L., Rydin, E., 2019. Levande kusts Vitbok 1.0. Report, BalticSea 2020, 2019-06-18, 124 pp. (In Swedish).

Lammens, E.H.R.R., 2001. Consequences of biomanipulation for fish and fisheries. FAO, Rome (Italy). Fishery Resources Div.

Larsson P., Tibblin, P., Koch-Schmidt, P., Engstedt, O., Nilsson, J., Nordahl, O., Forsman, A., 2015. Ecology, evolution, and management strategies of northern pike populations in the Baltic Sea. Ambio 44: 451-461.

Lehtoranta, J., Lännergren, C., Bendtsen, J., Pitkänen, H., Myrberg, K., Kuosa, H., 2012. Effects of oxygenation on the status of the pilot sites. In: Rantajärvi, E. (Ed.), Final Report on the Result of the PROPPEN Project Controlling Benthic Release of Phosphorus in Different Baltic Sea Scales (02-0301-08) to the Swedish Environmental Protection Agency, Formas and VINNOVA, pp 44-72.

Leppäkoski, E., Bonsdorff, E., 1989. Ecosystem variability and gradients. Examples from the Baltic Sea as a background for hazard assessment. In: Landner, L. (ed.), Chemicals in the Aquatic Environment, Springer Berlin Heidelberg, s. 6-58.

Lewis, L.J., Davenport, J., Kelly, T.C., 2002. A study of the impact of a pipeline construction on estuarine benthic invertebrate communities. Estuar Coast Shelf Sci 55:213-221.

Lewis, R.R., 2005. Ecological engineering for successful management and restoration of mangrove forests. Ecol Eng 24:403-418.

Lindahl, O., 2008. Musselodling för miljön – nu även i Östersjön. HavsUtsikt 3/2008, Stockholms Marina Forskningscentrum, s. 4-5. (In Swedish).

Lindahl, O., 2012. Mussel farming as an environmental measure in the Baltic. Final Report BalticSea2020, 18 pp.

Lindahl, U., 2014. Inventering av torrlagda havsvikar i Blekinge. Länsstyrelsen i Blekinge län, Rapport 2014:24, Dnr: 502-1774-2010, 110 s. (In Swedish).

Lindegarth, M., Ekelund, A., Bergström, P., Lundström, K., Granhed, A., Åhlund, M., Uddén, J., 2019. Slutrapport för projektet ”Utveckling av metoder och kunskap för att minska ejderpredation i blåmusselodlingar”. 45 s. (In Swedish).

Ljunggren, L., Olsson, J., Nilsson, N., Stenroth, P., Larsson, L., Engstedt, O., Borger, T., Sandström, O., 2011. Våtmarker som rekryteringsområden för gädda i Östersjön - erfarenhet och rekommendationer från ett forskningsprojekt. Fiskeriverket Informerar, Finfo 2011:1

López, I., Tinoco, H., Aragonés, L., García-Barba, J., 2016. The multifunctional artificial reef and its role in the defence of the Mediterranean coast. Sci Total Environ 550:910-923.

Lotze, H.K., Lenihan, H.S., Bourque, B.J., Bradbury, R.H., Cooke, R.G., Kay, M.C., Kidwell, S.M., Kirby, M.X., Peterson, C.H., Jackson, J.B.C., 2006. Depletion, degradation, and recovery potential of estuaries and coastal seas. Science 312:1806-1809.

Lotze, H.K., Coll, M., Magera, A.M., Ward-Paige, C., Airoldi, L., 2011. Recovery of marine animal populations and ecosystems. Trend Ecol Evol 26:595-605.

Malm, T., Engkvist, R., 2011. Bentiska processer på och runt artificiella strukturer i Sveriges kustvatten. Naturvårdsverket Rapport 6414. ISBN978-91-620-6414-3, 35 s. (In Swedish).

Malmaeus, M., Karlsson, M., 2013. Modellering av gödande ämnen i Björnöfjärdssystemet. IVL rapport B2135. IVL Svenska Miljöinstitutet. (In Swedish).

Martinsson, J., 2015. Betydelsen av bortforsling av alger för rekrytering av plattfisk på Gotland. Länsstyrelsen I Gotlands län, Visby, Rapportnummer 2015:12, 35 s. (In Swedish).

Meesters, H.W.G., Smith, S.R., Becking, L.E., 2015. A review of coral reef restoration techniques. No. C028/14. IMARES, Den Burg.

Mann, R., Powell, E.N., 2007. Why oyster restoration goals in the Chesapeake Bay are not and probably cannot be achieved. J Shellfish Res 26:905-917.

Marion, S.R., Orth, R.J., 2010. Innovative techniques for large-scale seagrass restoration using *Zostera marina* (eelgrass) seeds. Restor Ecology 18:514-526.

Mehner, T., Arlinghaus, R., Berg, S., Dörner, H., Jacobsen, L., Kasprzak, P., Koschel, R., Schulze, T., Skov, C., Wolter, C., Wysujack, K., 2004. How to link biomanipulation and sustainable fisheries management: a step-by-step guideline for lakes of the European temperate zone. Fisheries Manage Ecol 11:261-275.

Micheli, F., Halpern, B.S., Walbridge, S., Ciriaco, S., Ferretti, F., Fraschetti, S., Lewison, R., Nykjaer, L., Rosenberg, A.A., 2013. Cumulative human impacts on Mediterranean and Black Sea marine ecosystems: assessing current pressures and opportunities. PLoS ONE 8:e79889.

Mikkelsen, L., Mouritsen, K.N., Dahl, K., Teilmann, J., Tougaard, J., 2013. Re-established stony reef attracts harbour porpoises *Phocoena phocoena*. Mar Ecol Prog Ser 481:239-248.

Milon, J.W., 1989. Artificial marine habitat characteristics and participation behavior by sport anglers and divers. Bull Mar Sci 44:853-862.

Moksnes, P.-O., Gullström, M., Tryman, K., Baden, S., 2008. Trophic cascades in a temperate seagrass community. Oikos 117:763-777.

Moksnes, P.O., Gipperth, L., Eriander, L., Laas, K., Cole, S., Infantes, E., 2016a. Förvaltning och restaurering av ålgräs i Sverige – Ekologisk, juridisk och ekonomisk bakgrund. Havs- och vattenmyndighetens rapport 2016:8, 148 s, ISBN 978-91-87967-16-0. (In Swedish).

Moksnes, P.O., Gipperth, L., Eriander, L., Laas, K., Cole, S., Infantes, E., 2016b. Handbok för restaurering av ålgräs i Sverige – Vägledning. Havs- och vattenmyndighetens rapport 2016:9, 146 s, ISBN 978-91-87967-17-7. (In Swedish).

Moksnes, P.O., Eriander, L., Infantes, E., Holmer, M., 2018. Local regime shifts prevent natural recovery and restoration of lost eelgrass beds along the Swedish west coast. Estuar Coast 41:1712-1731.

Morris, J.P., Backeljau, T., Chapelle, G., 2019. Shells from aquaculture: a valuable biomaterial, not a nuisance waste product. Rev Aquacult 11:42-57.

Moy, F.E., Christie, H., 2012. Large-scale shift from sugar kelp (*Saccharina latissima*) to ephemeral algae along the south and west coast of Norway. Mar Biol Res 8:309-321.

Moy, F., Christie, H., Steen, H., Stålnacke, P., Aksnes, D., Alve, E., Aure, J., Bekkby, T., Fredriksen, S., Gitmark, J., Hackett, B., Magnusson, J., Pengerud, A., Sjøtun, K., Sørensen, K., Tveiten, L., Øygarden, L., Åsen, P.A., 2008. Sluttrapport fra Sukkertareprosjektet 2005-2008, SFT Report TA-2467/2008, NIVA Report 5709, 131 s..

Naturvårdsverket, 2016. Ekologisk kompensation. En vägledning om kompensation vid förlust av naturvärden. Handbok 2016:1, Utgåva 1. 111 s. (In Swedish).

Nilsson, J., Engstedt, O., Larsson, P., 2014. Wetlands for northern pike (*Esox lucius* L.) recruitment in the Baltic Sea. Hydrobiologia 721:145-154.

Niner, H.J., Jones, P.J.S., Milligan, B, Styan, C.A., 2017. A global snapshot of marine biodiversity offsetting policy. Mar Policy 81:368-374.

Norkko, A, Rosenberg, R., Thrush, S.F., Whitlatch, R.B., 2006. Scale- and intensity-dependent disturbance determines the magnitude of opportunistic response. J Exp Mar Biol Ecol 330:195-207.

Nyberg, J., Elhammer, A., Severin, M, Zillén Snowball, L., 2013. Maringeologi: Begäran om sektorsunderlag till kommande havsplanering. Sveriges Geologiska Undersökning/Havs- och vattenmyndigheten. (In Swedish).

Ogdahl, M.E., Steinman, A.D., 2015. Factors influencing macrophyte growth and recovery following shoreline restoration activity. Aquat Bot 120:363-370.

Ollikainen, M., Zandersen, M., Bendtsen, J., Lehtoranta, J., Saarijärvi, E., Pitkänen, H., 2016. Any payoff to ecological engineering? Cost-benefit analysis of pumping oxygen-rich water to control benthic release of phosphorus in the Baltic Sea. Water Resour Econ 16:28-38.

Olsson, P., Folke, C., Hahn, T., 2004. Social-ecological transformation for ecosystem management: the development of adaptive co-management of a wetland landscape in southern Sweden. Ecol Soc 9:2.

Orth, R.J., Harwell, M.C., Fishman, J.R., 1999. A rapid and simple method for transplanting eelgrass using single, unanchored shoots. Aquat Bot 64:77-85.

Orth, R.J., Moore, K.A., Marion, S.R., Wilcox, D.J., Parrish, D.B., 2011. Seed addition facilitates eelgrass recovery in a coastal bay system. Mar Ecol Prog Ser 448:177-195.

OSPAR COMMISSION, 2009. Assessment of construction or placement of artificial reefs. London: Biodiversity Series, publ. no. 438/2009, 2009, 27 p.

Österblom, H., Crona, B.I., Folke, C., Nyström, M., Troell, M., 2017. Marine ecosystem science on an intertwined planet. Ecosystems 20:54–61.

Östman, Ö., Eklöf, J., Eriksson, B.K., Olsson, J., Moksnes, P.-O., Bergström, U., 2016. Top-down control as important as nutrient enrichment for eutrophication effects in North Atlantic coastal ecosystems. J Appl Ecol 53:1138-1147.

Ounanian, K., Carballo-Cardenas, E., Van Tatenhove, J.P.M., Delaney, A., Papadopoulou, K.N., Smith, C.J., 2018. Governing marine ecosystem restoration: the role of discourses and uncertainties. Mar Pol 96: 136-144.

Pajusalu, L., Bakran-Petricioli, T., Boström, C., Carugati, L., Christie, H., Da Ros, Z., Danovaro, R., Gagnon, K., Gambi, C., Govers, L., Gräfnings, M., Kaljurand, K., Kipson, S., Kotta, J., Martire, M.L., Rinde, E., van der Heide, T., van de Koppel, J., Martin, G., 2019. Restoration results in the case study sites. Deliverable 2.2. MERCES project, 53 pp.

Pålsson, C. (ed.), 2009. Inventering av behovet och möjligheterna till restaurering av övergödda havsvikar och kustnära sjöar (Södra Östersjöns vattendistrikt) – redovisning av regeringsuppdrag. Länsstyrelsen i Kalmar län, Kalmar. (In Swedish).

Park, J.I., Lee, K.-S., 2007. Site-specific success of three transplanting methods and the effect of planting time on the establishment of *Zostera marina* transplants. Mar Poll Bull 54:1238-1248.

Perkol-Finkel, S., Ferrario, F., Nicotera, V., Airoldi, L., 2012. Conservation challenges in urban seascapes: promoting the growth of threatened species on coastal infrastructures. J Appl Ecol 49:1457-1466.

Pihl, L., 2001. Effekter av fintrådiga alger på rekrytering av rödspotta: en numerisk modell. Länsstyrelsen. (In Swedish).

Pioch, S., Kilfoyle, K., Levrel, H., Spieler, R., 2011. Green marine construction. J Coast Res 61:257-268.

Pitkänen, H., Bendtsen, J., Hansen, J.L., Lehtoranta, J., Lännergren, C., Ollikainen, M., Priha, M., Reinikainen, M., Saarijärvi, E., Zandersen, M., 2012. Controlling benthic release of phosphorus in different Baltic Sea scales: Final Report on the result of the PROPPEN Project (802-0301-08), Finnish Environmental Institute, Helsinki.

Ponti, M., Fava, F., Perlini, R.A., Giovanardi, O., Abbiati, M., 2015. Benthic assemblages on artificial reefs in the northwestern Adriatic Sea: Does structure type and age matter? Mar Environ Res 104:10-19.

Reed, D., Schroeter, S., Page, M. (Eds), 2002. Proceedings from the Second Annual Public Workshop for the SONGS Mitigation Project. Report to the California Coastal Commission. University of California, Santa Barbara. Marine Science Institute.

Reed, D.C., Slomp, C.P., Gustafsson, B.G., 2011. Sedimentary phosphorus dynamics and the evolution of bottom-water hypoxia: A coupled benthic-pelagic model of a coastal system. Limnol Oceanogr 56:1075-1092.

Reutersköld, D., 2012. Hotade natearter. Utplantering och uppföljning i Skåne under 2008-2011. Rapport 2012:4. Länsstyrelsen i Skåne, Malmö. (In Swedish).

Rodrigo, M.A., Rojo, C., Alonso-Guillén, J.L., Vera, P., 2013. Restoration of two small Mediterranean lagoons: the dynamics of submerged macrophytes and factors that affect the success of revegetation. Ecol Eng 54:1-15.

Rodrigo, M.A., Rojo, C., Segura, M., Alonso-Guillén, J.L., Martín, M., Vera, P., 2015. The role of charophytes in a Mediterranean pond created for restoration purposes. Aquat Bot 120:101-111.

Rostmark, S.C., Colombo, M., Knutsson, S., Öberg, G., 2015. Removal and re-use of tar-contaminated sediments by freeze-dredging at a coking plant Lulea, Sweden. Water environment research: a research publication of the Water Environment Federation.

Rouanet, E., Astruch, P., Antonioli, A., Bonhomme, P., Fourt, M., Bonhomme, D., Goujard, A., Le Diréach, L., Perez, T., 2015. How artificial reefs design and architectural complexity affects the benthic colonization. In: Proceedings of the RECIFS Conference on Artificial Reefs: From Materials to Ecosystems. ESITC, Caen, pp 53-60.

Russell, G., Hawkins, S.J., Evans, L.C., Jones, H.D., Holmes, G.D., 1983. Restoration of a disused dock basin as a habitat for marine benthos and fish. J Appl Ecol 20:43-58.

Ruuskanen, A.T., Kraufvelin, P., Alvik, R., Díaz, E.R., Honkonen, J., Kanerva, J., Karell, K., Kekäläinen, P., Lappalainen, J., Mikkola, R., Mustasaari, T., Nappu, N., Nieminen, A., Roininen, J., Svahnbäck, K., 2015. Benthic conditions around a historic shipwreck: Vrouw Maria (1771) in the northern Baltic proper. Cont Shelf Res 98:1-12.

Rydin, E., 2014. Inactivated phosphorus by added aluminium in Baltic Sea sediment. Estuar Coast Shelf Sci 151:181-185.

Rydin, E., Kumblad, L., Wulff, F., Larsson, P., 2017. Remediation of a eutrophic bay in the Baltic Sea. Environ Sci Technol 51:4559-4566.

Rydin, E., Kumblad, L., 2019. Capturing past eutrophication in coastal sediments – Towards water-quality goals. Estuar Coast Shelf Sci 221:184-188.

Saarinen, A., 2019. Restaurering av grunda kustmiljöer i Kvarken – Erfarenheter, metoder och framtida åtgärder med fokus på flador. Delrapport inom Interreg Botnia Atlantica projekt Kvarken Flada. s. 57. (In Swedish)

Sagerman, J., Hansen, J., Wikström, S.A., 2020. Effects of boat traffic and mooring infrastructure on aquatic vegetation: A systematic review and meta-analysis. Ambio 49:517-530.

Sandell, G., Karås, P., 1995. Små sötvatten som lek och uppväxtmiljöer för kustfiskbestånd – försummad och hotad resurs? I. Bevarande och restaurering av reproduktionsmiljöer för fisk i vattendrag. Kustrapport 1995:2. Fiskeriverket, Öregrund, 46 s. (In Swedish).

Sandström, A., 2003. Restaurering och bevarande av lek- och uppväxtområden för kustfiskbestånd. Fiskeriverket informerar 2003:3, 26 s. (In Swedish).

Sandström, A., Eriksson, B.K., Karås, P., Isæus, M., Schreiber, H., 2005. Boating and navigation activities influence the recruitment of fish in a Baltic Sea archipelago area. Ambio 34: 125-130.

Sandström, O., 2011. Reduktionsfiske som metod för att minska övergödningen i Östhammarsfjärdarna. Upplandsstiftelsen, Rapport 2011/2. (In Swedish). http://www.upplandsstiftelsen.se/UserFiles/Archive/5417/Rapporter/2011_2_Reduktionsfiske.pdf

Salonsaari, J., 2009. Övergödda havsvikar och kustnära sjöar inom Norra Östersjöns vattendistrikt – redovisning av regeringsuppdrag, Rapport nr 2009:5. Länsstyrelsen i Västmanlands län, Västerås. (In Swedish).

Scheffer, M., Carpenter, S., Foley, J.A., Folke, C., Walker, B., 2001. Catastrophic shifts in ecosystems. Nature 413:591-596.

Schroeter, S.C., Reed, D.C., Raimondi, P.T., 2015. Effects of reef physical structure on development of benthic reef community: a large-scale artificial reef experiment. Mar Ecol Prog Ser 540:43-55.

Seaman, W., 2007. Artificial habitats and the restoration of degraded marine ecosystems and fisheries. Hydrobiologia 580:143-155.Rydin, E., 2014. Inactivated phosphorus by added aluminium in Baltic Sea sediment. Estuar Coast Shelf Sci 151:181-185.

Seddon, S., 2004. Going with the flow: Facilitating seagrass rehabilitation. Ecol Manage Restor 5:167-176.

Shafer, D., Bergstrom, P., 2010. An introduction to a special issue on large-scale submerged aquatic vegetation restoration research in the Chesapeake Bay: 2003–2008. Restor Ecol 18:481-489.

Sharma, S., Goff, J., Moody, R.M., Byron, D., Heck, K.L., Powers, S.P., Ferraro, C., Cebrian, J., 2016. Do restored oyster reefs benefit seagrasses? An experimental study in the Northern Gulf of Mexico. Restor Ecol 24:306-313.

Short F.T., Davis R.C., Kopp B.S., Short C.A., Burdick D.M. 2002. Site-selection model for optimal transplantation of eelgrass *Zostera marina* in the northeastern US. Mar Ecol Prog Ser 227:253-267.

Silva, R., Mendoza, E., Marino-Tapia, I., Martínez, M.L., Escalante, E., 2016. An artificial reef improves coastal protection and provides a base for coral recovery. J Coast Res 75:467-471.

Simenstad, C., Reed, D., Ford, M., 2006. When is restoration not? Incorporating landscape-scale processes to restore self-sustaining ecosystems in coastal wetland restoration. Ecol Eng 26:27-39.

Smart, R.M., Dick, G.O., 1999. Propagation and establishment of aquatic plants: a handbook for ecosystem restoration projects (No. WES-TR-A-99-4). Army Engineer Waterways Experiment Station Vicksburg MS.

Smith, J.A., Lowry, M.B., Champion, C., Suthers, I.M., 2016. A designed artificial reef is among the most productive marine fish habitats: new metrics to address ‘production versus attraction’. Mar Biol 163:188.

Søndergaard, M., Liboriussen, L., Pedersen, A.R., Jeppesen, E., 2008. Lake restoration by fish removal: short- and longterm effects in 36 Danish lakes. Ecosystems 11:1291-1305.

Stadmark, J., Conley, D.J., 2011. Mussel farming as a nutrient reduction measure in the Baltic Sea: Consideration of nutrient biogeochemical cycles. Mar Pollut Bull 62:1385-1388.

Staszak, L.A., Armitage, A.R., 2012. Evaluating salt marsh restoration success with an index of ecosystem integrity. J Coast Res 29:410-418.

Stenberg, C., Støttrup, J.G., van Deurs, M., Berg, C.W., Dinesen, G.E., Mosegaard, H., Grome, T.M., Leonhard, S.B., 2015. Long-term effects of an offshore wind farm in the North Sea on fish communities. Mar Ecol Prog Ser 528:257-265.

Stewart-Oaten, A., Murdoch, W.W., Parker, K.R., 1986. Environmental impact assessment:" Pseudoreplication" in time? Ecology 67:929-940.

Stigebrandt, A., 2018. On the response of the Baltic proper to changes of the total phosphorus supply. Ambio 47:31-44.

Stigebrandt, A., Gustafsson, B.G., 2007. Improvement of Baltic proper water quality using large-scale ecological engineering. Ambio 36:280-286.

Stigebrandt, A., Liljebladh, B., De Brabandere, L., Forth, M., Granmo, Å., Hall, P., Hammar, J., Hansson, D., Kononets, M., Magnusson, M., Norén, F., Rahm, L., Treusch, A.H., Viktorsson, L., 2015. An experiment with forced oxygenation of the deepwater of the anoxic By Fjord, western Sweden. Ambio 44:42-54.Lewis, L.J., Davenport, J., Kelly, T.C., 2002. A study of the impact of a pipeline construction on estuarine benthic invertebrate communities. Estuar Coast Shelf Sci 55:213-221.

Stocks, K.I., Grassle, J.F., 2001. Effects of microalgae and food limitation on the recolonization of benthic macrofauna into in situ saltmarsh-pond mesocosms. Mar Ecol Prog Ser 221: 93-104.

Støttrup, J.G., Stenberg, C., Dahl, K., Kristensen, L.D., Richardson, K., 2014. Restoration of a temperate reef: effects on the fish community. Open J Ecol 4:1045-1059.

Støttrup, J.G., Dahl, K., Niemann, S., Stenberg, C., Reker, J., Stamphoj, E.M., Goke, C., Svendsen, J.C., 2017. Restoration of a boulder reef in temperate waters: Strategy, methodology and lessons learnt. Ecol Eng 102:468-482.

Strand, J.A., Weisner, S.E.B., 2013. Effects of wetland construction on nitrogen transport and species richness in the agricultural landscape – Experiences from Sweden. Ecol Eng 56:14-25.

Sundblad, G., Bergström, U., 2014. Shoreline development and degradation of coastal fish reproduction habitats. Ambio 43: 1020-1028.

Sundblad, G., Bergström, U., Sandström, A., Eklöv, P., 2014. Nursery habitat availability limits adult stock sizes of predatory coastal fish. ICES J Mar Sci 71:672-680.Torn, K., Martin, G., Kotta, J., Kupp, M., 2010. Effects of different types of mechanical disturbances on a charophyte dominated macrophyte community. Estuar Coast Shelf Sci 87:27-32.

Svane, I.B., Petersen, J.K., 2001. On the problems of epibioses, fouling and artificial reefs, a review. Mar Ecol 22:169-188.

Svedberg, K., 2019. Musselbankar: nulägesanalys och beståndsförstärkning. Magistersarbete, Göteborgs universitet, Göteborg, 41 s. (In Swedish).

Taylor, D., Saurel, C., Nielsen, P., Petersen, J.K., 2019. Production characteristics and optimization of mitigation mussel culture. Front Mar Sci 6:698.

Tibblin, P., Forsman, A., Borger, T., Larsson, P., 2016. Causes and consequences of repeatability, flexibility and individual fine-tuning of migratory timing in pike. J Anim Ecol 85:136-145.

Torn, K., Martin, G., Kotta, J., Kupp, M., 2010. Effects of different types of mechanical disturbances on a charophyte dominated macrophyte community. Estuar Coast Shelf Sci 87:27-32.

Tracey, S., Mundy, C., Baulch, T., Marzloff, M., Hartmann, K., Ling, S., Tisdell, J., 2014. Trial of an industry implemented, spatially discrete eradication/control program for *Centrostephanus rodgersii* in Tasmania. Fisheries Research and Development Coorporation project no. 2011/087.

Underwood, A.J., 1994. On beyond BACI: sampling designs that might reliably detect environmental disturbances. Ecol Appl 4:3-15.

Ushiama, S., Smith, J.A., Suthers, I.M., Lowry, M., Johnston, E.L., 2016. The effects of substratum matter and surface orientation on the developing epibenthic community on a designed artificial reef. Biofouling 32:1049-1060.

Ushiama, S., Mayer-Pinto, M., Bugnot, A.B., Johnston, E.L., Dafforn, K.A., 2019. Eco-engineering increases habitat availability and utilization of seawalls by fish. Ecol Eng 138:403-411.

van Katwijk, M.M., Schmitz, G.H., Hanssen, L.S., den Hartog, C., 1998. Suitability of *Zostera marina* populations for transplantation to the Wadden Sea as determined by a mesocosm shading experiment. Aquat Bot 60:283-305.

Van Katwijk, M.M., Bos, A.R., De Jonge, V.N., Hanssen, L.S.A.M., Hermus, D.C.R., De Jong, D.J., 2009. Guidelines for seagrass restoration: importance of habitat selection and donor population, spreading of risks, and ecosystem engineering effects. Mar Pollut Bull 58:179-188.

van Katwijk, M.M., Thorhaug, A., Marbà, N., Orth, R.J., Duarte, C.M., Kendrick, G.A., Althuizen, I.H.J., Balestri, E., Bernard, G., Cambridge, M.L., Cunha, A., Durance, C., Giesen, W., Han, Q., Hosokawa, S., Kiswara, W., Komatsu, T., Lardicci, C., Lee, K.-S., Meinesz, A., Nakaoka, M., O'Brien, K.R., Paling, E.I., Pickerell, C., Ransijn, A.M.A., Verduin, J.J., 2016. Global analysis of seagrass restoration: the importance of large-scale planting. J Appl Ecol 53:567-578.

Van Nes, E.H., Scheffer, M., van den Berg, M.S., Coops, H., 2002. Aquatic macrophytes: restore, eradicate or is there a compromise? Aquat Bot 72:387-403.

Verdonschot, P.F.M., Spears, B.M., Feld, C.K., Brucet, S., Keizer-Vlek, H., Borja, A., Elliott, M., Kernan, M., Johnson, R.K., 2013. A comparative review of recovery processes in rivers, lakes, estuarine and coastal waters. Hydrobiologia 704:453-474.

Verdura, J., Sales, M., Ballesteros, E., Cefalì, M.E., Cebrian, E., 2018. Restoration of a canopy-forming alga based on recruitment enhancement: methods and long-term success assessment. Front Plant Sci 9:1832.

Walles, B., Troost, K., van den Ende, D., Nieuwhof, S., Smaal, A.C., Ysebaert, T., 2016. From artificial structures to self-sustaining oyster reefs. J Sea Res 108:1-9.

Warren, R.S., Fell, P.E., Rozsa, R., Brawley, A.H., Orsted, A.C., Olson, E.T., Swamy, V., Niering, W.A., 2002. Salt marsh restoration in Connecticut: 20 years of science and management. Restor Ecol 10:497-513.

Wasserman, J.C., Barros, S.R., Lima, G.B.A., 2013. Planning dredging services in contaminated sediments for balanced environmental and investment costs. J Environ Manage 121:48-56.

Westermeier, R., Murúa, P., Patiño, D.J., Muñoz, L., Atero, C., Müller, D.G., 2014. Repopulation techniques for *Macrocystis integrifolia* (Phaeophyceae: Laminariales) in Atacama, Chile. J Appl Phycol 26:511-518.

Wikström, A., Sundqvist, F., Ulmestrand, M., Wennhage, H., Bergström, U., 2016. Ett fiskefritt område för skydd av hummer och rovfisk i Göteborgs skärgård. S. 159-180 i: Bergström et al. 2016. Ekologiska effekter av fiskefria områden i Sveriges kust- och havsområden. Aqua reports 2016:20, Institutionen för akvatiska resurser, Sveriges lantbruksuniversitet, Öregrund. (In Swedish).

Wikström, S.A., Hedberg, N., Kautsky, N., Kumblad, L., Ehrnsten, E., Gustafsson, B., Humborg, C., Norkko, A., Stadmark, J. (2020). Letter to editor regarding Kotta et al. 2020: Cleaning up seas using blue growth initiatives: Mussel farming for eutrophication control in the Baltic Sea. Sci Total Environ 727:138665.

Wilhelmsson, D., Malm, T., 2008. Fouling assemblages on offshore wind power plants and adjacent substrata. Estuar Coast Shelf Sci 79:459-466.

Wilhelmsson, D., Malm, T., Öhman, M.C., 2006. The influence of offshore windpower on demersal fish. ICES J Mar Sci 63:775-784.

Worm, B., 2016. Averting a global fisheries disaster. P Natl Acad Sci 113:4895-4897.

Worm, B., Reusch, T.B., 2000. Do nutrient availability and plant density limit seagrass colonization in the Baltic Sea? Mar Ecol Prog Ser 200:159-166.

Yang, C.J., Liu, Y.S., Liu, J., Xu, Q., Li, W.T., Zhang, P.D., 2016. Assessment of the establishment success of *Zostera marina* (eelgrass) from seeds in natural waters: Implications for large-scale restoration. Ecol Eng 92:1-9.

Yoon, J.T., Sun, S.M., Chung, G., 2014. *Sargassum* bed restoration by transplantation of germlings grown under protective mesh cage. J Appl Phycol 26:505-509.

Zedler, J.B., Callaway, J.C., 1999. Tracking wetland restoration: do mitigation sites follow desired trajectories? Restor Ecol 7:69-73.

Zeffer, A., 2015. Metodutveckling för restaurering av hummerbiotoper med avsikt att öka tillgången på hummer och storvuxen torsk i 8-fjordarområdet. Rapport, 8-fjordar, Stenungsund. (In Swedish).

Zhang, C., Zhu, M.Y., Zeng, G. ., Yu, Z.G., Cui, F., Yang, Z.Z., Shen, L.Q., 2016. Active capping technology: a new environmental remediation of contaminated sediment. Environ Sci Pollut Res 23:4370-4386.

Zhang, P.D., Fang, C., Liu, J., Xu, Q., Li, W.T., Liu, Y.S., 2015. An effective seed protection method for planting *Zostera marina* (eelgrass) seeds: Implications for their large-scale restoration. Mar Pollut Bull 95:89-99.

Zhao, J.S., Liu, Y.S., Zhang, P.D., Li, W.T., Fang, C., 2016. Assessment of the establishment success of eelgrass *Zostera marina* (Alismatales: Zosteraceae) from seeds in a cost-effective seed protection method: implications for large-scale restoration. Bot Mar 59:259-266.

Zhao, Q., Bai, J., Huang, L., Gu, B., Lu, Q., Gao, Z., 2016. A review of methodologies and success indicators for coastal wetland restoration. Ecol Indic 60:442-452.

Zhou, Y., Liu, P., Liu, B., Liu, X., Zhang, X., Wang, F., Yang, H., 2014. Restoring eelgrass (Zostera marina L.) habitats using a simple and effective transplanting technique. PLoS ONE 9:e92982.

Zinko, U., 2017. Kunskapsuppbyggande program – 16 hotade makrofytarter i permanenta vatten. Havs- och vattenmyndighetens rapport 2017:6. Havs- och vattenmyndigheten, Göteborg. (In Swedish).

Zweifel, U.L., 2008. Marin syntes. Rapport 5715/Maj 2008. Naturvårdsverket, Stockholm. 109 s. ISBN 91-620-5715-4.

Appendix 1. Obtained averaged scores for each combination of criterion and restoration measure from the expert evaluation by 12 experts.

Averaged evaluation of restoration targets/methods done by 12 experts	**1. Eelgrass**	**2. Angiosperms**	**3. Macroalgae**	**4. Mussel reefs**	**5. Stony reefs**	**6. Unveg. soft bottom**	**7. Coastal wetlands**	**8. Piscivorous fish**	**9. Mussel farming**	**10. Oxygen pumping**	**11. P metal binding**	**12. Biomanipulation**	**13. Polluted sediments**	**14. Artificial reefs**	**15. Habitat protection**
Biodiversity and habitat	3,0	2,8	2,6	2,8	2,1	1,5	2,8	2,1	1,3	1,0	1,3	1,5	1,4	1,8	2,8
Ecosystem services and values	3,0	2,8	2,9	2,9	2,6	1,9	3,0	2,6	1,7	1,9	2,0	2,1	1,7	2,1	2,9
Environmental risk of no action	1,7	2,1	1,7	1,9	1,3	1,3	2,3	2,3	1,2	1,1	1,5	1,3	1,7	1,1	3,0
Restoration type	2,8	2,9	2,8	3,0	2,9	2,6	2,9	2,0	1,5	2,0	1,8	1,5	2,2	2,1	1,7
Focus on symptoms or causes	1,5	1,3	1,3	1,4	1,7	1,2	2,5	2,1	1,4	1,2	1,2	1,3	1,4	1,2	2,5
Method availability	2,2	1,3	2,0	1,9	2,7	1,3	2,8	2,4	2,1	1,6	2,3	2,1	2,3	2,6	2,7
Practical experiences	2,7	2,2	3,0	2,6	2,9	1,9	3,0	2,8	2,9	2,4	2,4	2,6	2,6	2,8	2,9
Long-term success	1,7	1,8	1,2	2,0	2,6	1,7	2,8	1,7	1,6	1,0	1,6	1,2	1,7	2,1	2,8
Needs for complementary measures	0,5	0,7	0,5	1,4	1,7	1,2	2,3	0,9	1,1	0,3	0,5	0,7	1,0	1,1	1,1
Risks of negative side-effects	2,7	2,5	2,7	2,4	1,8	1,5	1,9	1,9	1,7	0,6	1,2	1,2	0,9	1,4	2,5
Size of area affected positively	1,6	1,6	1,4	1,8	1,9	1,6	2,2	2,2	1,8	1,7	1,2	2,0	1,2	1,6	2,3
Costs effectiveness associated	1,0	1,2	1,0	1,6	2,0	1,6	2,7	2,6	1,6	1,0	1,5	1,7	1,4	1,8	2,9
Sum-up	24,5	23,3	23,1	25,7	26,3	19,3	31,2	25,6	19,8	15,8	18,5	19,2	19,5	21,7	30,1

Appendix 2. Calculated SD (standard deviations) as a metric of certainty for scores given for each combination of criterion and restoration measure from the expert evaluation by 12 experts.

SD for evaluation of restoration targets/methods done by 12 experts	**1. Eelgrass**	**2. Angiosperms**	**3. Macroalgae**	**4. Mussel reefs**	**5. Stony reefs**	**6. Unveg. soft bottom**	**7. Coastal wetlands**	**8. Piscivorous fish**	**9. Mussel farming**	**10. Oxygen pumping**	**11. P metal binding**	**12. Biomanipulation**	**13. Polluted sediments**	**14. Artificial reefs**	**15. Habitat protection**
Biodiversity and habitat	0,0	0,4	0,5	0,4	0,8	0,7	0,4	0,8	0,6	0,0	0,5	0,8	0,5	0,7	0,4
Ecosystem services and values	0,0	0,4	0,3	0,3	0,5	0,8	0,0	0,7	0,7	0,8	0,7	0,8	0,6	0,7	0,3
Environmental risk of no action	0,6	0,7	0,6	0,8	0,5	0,4	0,6	1,0	0,7	0,8	0,7	0,9	0,9	0,8	0,0
Restoration type	0,4	0,3	0,4	0,0	0,3	0,5	0,3	0,6	0,5	0,6	0,7	0,7	0,6	0,5	1,0
Focus on symptoms or causes	0,8	0,6	0,6	0,8	0,7	0,4	0,8	0,8	0,6	0,4	0,4	0,4	0,6	0,4	0,5
Method availability	0,7	0,5	0,8	0,8	0,6	0,5	0,4	0,7	0,8	0,5	0,6	0,5	0,6	0,8	0,6
Practical experiences	0,5	1,0	0,0	0,5	0,3	1,4	0,0	0,6	0,3	0,8	1,0	0,7	0,8	0,4	0,3
Long-term success	0,5	0,6	0,4	0,8	0,5	0,5	0,4	0,7	0,8	0,0	0,5	0,4	0,6	0,5	0,4
Needs for complementary measures	0,5	0,4	0,5	0,9	0,9	1,1	0,6	0,8	1,1	0,4	0,7	0,7	1,0	0,9	1,0
Risks of negative side-effects	0,4	0,5	0,4	0,6	0,4	0,9	0,7	0,9	0,9	0,8	0,7	0,9	0,7	0,5	1,0
Size of area affected positively	0,7	0,7	0,5	0,6	0,5	0,7	0,6	0,6	0,7	0,9	0,4	0,4	0,4	0,7	0,8
Costs effectiveness associated	0,0	0,6	0,0	0,7	0,8	0,7	0,6	0,7	0,5	0,0	0,7	0,6	0,5	0,7	0,3
	0,42	0,55	0,42	0,59	0,57	0,70	0,45	0,75	0,69	0,50	0,62	0,67	0,65	0,64	0,54